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GEOLOGICAL SURVEY OF ALABAMA

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DIVISION OF WATER RESOURCES

Doyle B. Knowles
Chief Hydraulic Engineer

BULLETIN 76

GEOLOGY AND GROUND-WATER RESOURCES OF MORGAN COUNTY, ALABAMA

By Chester L. Dodson and Wiley F. Harris, Jr.

with a section on the

CHEMICAL QUALITY OF THE WATER

By James C. Warman

Prepared by the United States Geological Survey
in cooperation with the
Morgan County Board of Revenue and Control,
the City of Decatur, and the
Geological Survey of Alabama

The nomenclature in this report is that of the Geological Survey of Alabama and does not necessarily follow that in use by the U.S. Geological Survey

UNIVERSITY, ALABAMA
1965

STATE OF ALABAMA

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June 30, 1965

Honorable George C. Wallace
Governor of Alabama
Montgomery, Alabama

Dear Governor Wallace:

I have the honor to transmit the manuscript of a report entitled "Geology and Ground-Water Resources of Morgan County, Alabama," by Chester L. Dodson and Wiley F. Harris, Jr., with a section on the "Chemical Quality of the Water" by James C. Warman, with the request that it be printed as Bulletin 76 of the Geological Survey of Alabama.

The report points out that the largest quantities of ground water in the county are obtained from solution cavities in the Fort Payne Chert. Wells that will yield 100 gallons per minute or more from the Fort Payne Chert are common in Morgan County; the largest yield is estimated at 1,100 gallons per minute. Water in adequate quantity and of satisfactory quality for domestic use is available in most parts of the county.

Respectfully,

Philip E LaMoreaux

Philip E. LaMoreaux
State Geologist

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GEOLOGY AND GROUND-WATER RESOURCES OF MORGAN COUNTY, ALABAMA

By Chester L. Dodson and Wiley F. Harris, Jr.

ABSTRACT

Morgan County includes an area of 587 square miles in north Alabama. Ground water occurs chiefly in solution cavities and openings along fractures and joint systems in limestone of Mississippian age. The principal aquifer is composed of the Tuscumbia Limestone and the Fort Payne Chert. Aquifers of less importance are in the Ste. Genevieve Limestone, Gasper Formation, Hartselle Sandstone, Bangor Limestone, and Pennington Formation.

Wells that will yield 100 gpm (gallons per minute) or more from the Fort Payne Chert or Tuscumbia Limestone are common in the Tennessee Valley physiographic district. Similar yields could be obtained from wells drilled in the Moulton Valley physiographic district. The largest yield from a well in Morgan County is estimated to be about 1,100 gpm. This well obtains water from the Fort Payne Chert. Few wells fully penetrate the Tuscumbia-Fort Payne aquifer so that at present only a small part of the aquifer is developed. Wells tapping the Hartselle Sandstone or the Pottsville Formation generally yield less than 10 gpm.

The chemical quality of ground water is generally suitable for most uses. However, water from the Fort Payne Chert to the contact between the Ste. Genevieve Limestone and the Gasper Formation is generally very hard. Locally the water is high in hydrogen sulfide or contains excessive iron.

INTRODUCTION

Morgan County includes an area of 587 square miles in north Alabama (fig. 1). Almost all the county lies within the drainage basin of the Tennessee River, which is the north boundary of the county. Flint Creek and Cotaco Creek are the main streams within the county. The topography is characterized by broad open valleys, plateaus bordered by escarpments, and a few isolated hills. The total relief is about 780 feet. The lowest area is along the shoreline of Wheeler Reservoir at an altitude of about 550 feet, and the highest point is in the NW$\frac{1}{4}$ sec. 27, T. 6 S., R. 1 W., at an altitude of about 1,330 feet.

According to the 1960 census, the population of the county is 60,454. The population of Decatur, the largest city, is 29,217, and that of Hartselle, the second largest city, is 5,000. The county is served by land, water, and air transportation, including two main-line railroads, three Federal and four State highways, several river barge lines, and one airline.

The climate of the county is mild. The average annual temperature is about 61° F; the average winter temperature is about 40° F; and the average summer temperature is about 80° F. The average annual precipitation is about 50 inches and is mostly in the form of rain, though snow is common in winter. Winter is the wettest season of the year, and early fall is the driest; January is usually the wettest month and October the driest. The normal monthly precipitation at Decatur is shown in figure 2. The growing season is about 200 days, from April to about the end of September.

The investigation of Morgan County was made by the U.S. Geological Survey in cooperation with the Morgan County Board of Revenue and Control, Mr. Guy D. Roberts, Chairman, the city of Decatur, Mr. Murray Dodd, Mayor, and the Geological Survey of Alabama, Philip E. LaMoreaux, State Geologist.

PURPOSE, SCOPE, AND METHODS OF INVESTIGATION

The investigation was made to determine the occurrence, availability, and quality of ground water in Morgan County to aid in the development of this resource for agricultural, municipal, industrial, and domestic use.

The study consisted of five main phases: collecting data from wells and springs, geologic mapping, determining the chemical quality of the ground water, drilling and pumping test wells, and writing a comprehensive report on the geology and ground-water resources of the county. As a part of the evaluation of the ground-water resources, 2,548 wells and springs were inventoried; data were collected on type

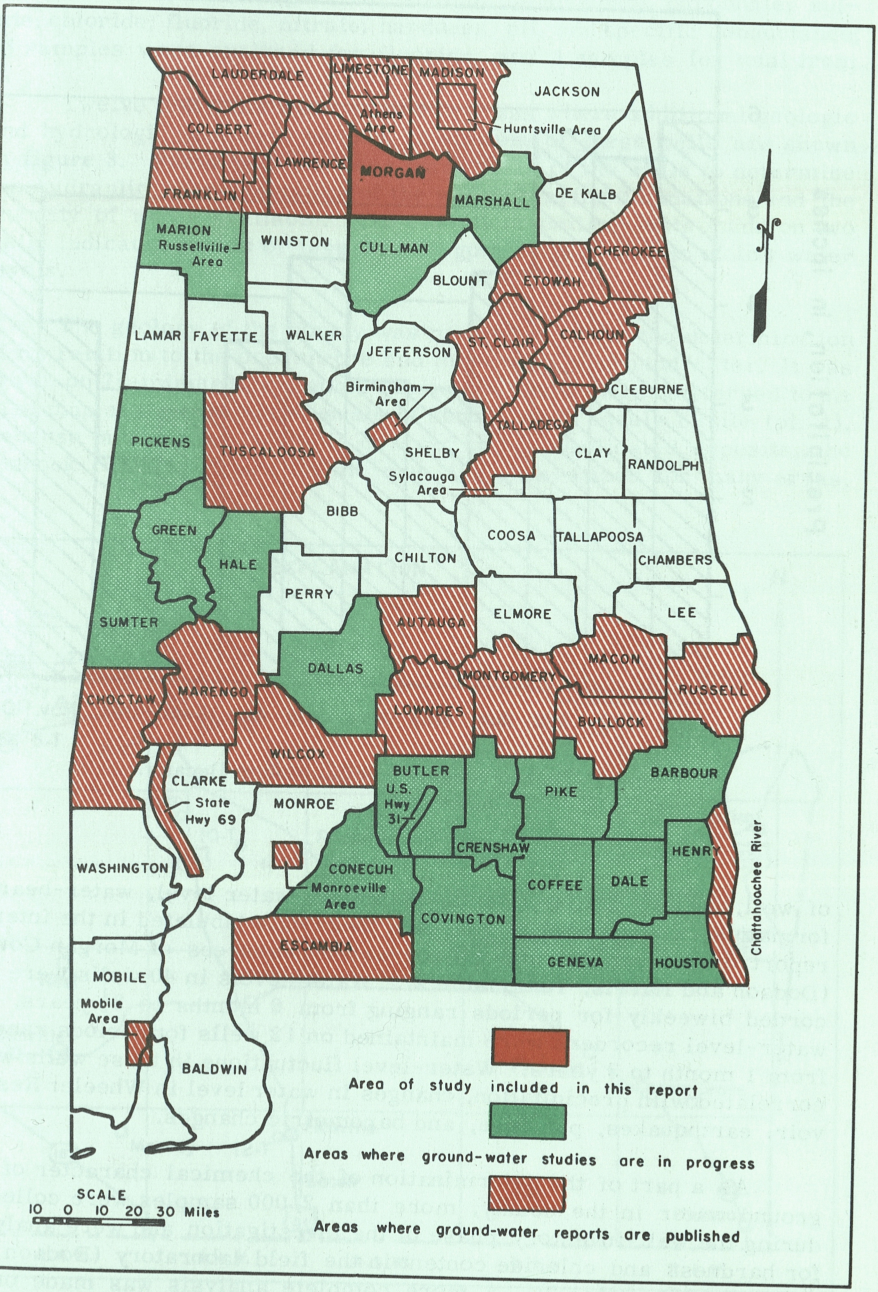

LAUDERDALE
LIMESTONE
MADISON
Athens Area
Huntsville Area
JACKSON
COLBERT
LAWRENCE
MORGAN
FRANKLIN
MARSHALL
DE KALB
MARION
Russellville Area
WINSTON
CULLMAN
CHEROKEE
BLOUNT
ETOWAH
LAMAR
FAYETTE
WALKER
JEFFERSON
ST. CLAIR
CALHOUN
Birmingham Area
CLEBURNE
PICKENS
TUSCALOOSA
TALLADEGA
SHELBY
CLAY
RANDOLPH
Sylacauga Area
BIBB
GREEN
COOSA
TALLAPOOSA
HALE
CHILTON
CHAMBERS
PERRY
SUMTER
AUTAUGA
ELMORE
LEE
DALLAS
MACON
CHOCTAW
MARENGO
MONTGOMERY
RUSSELL
LOWNDES
BULLOCK
WILCOX
BUTLER
U.S. Hwy 31
PIKE
BARBOUR
CLARKE
State Hwy 69
MONROE
CRENSHAW
HENRY
WASHINGTON
CONECUH
Monroeville Area
COFFEE
DALE
COVINGTON
ESCAMBIA
GENEVA
HOUSTON
Chattahoochee River
MOBILE
Mobile Area
BALDWIN
N
Area of study included in this report
Areas where ground-water studies are in progress
Areas where ground-water reports are published
SCALE
10 0 10 20 30 Miles

Figure 1.–Area studied and areas of other ground-water studies in Alabama, 1963.

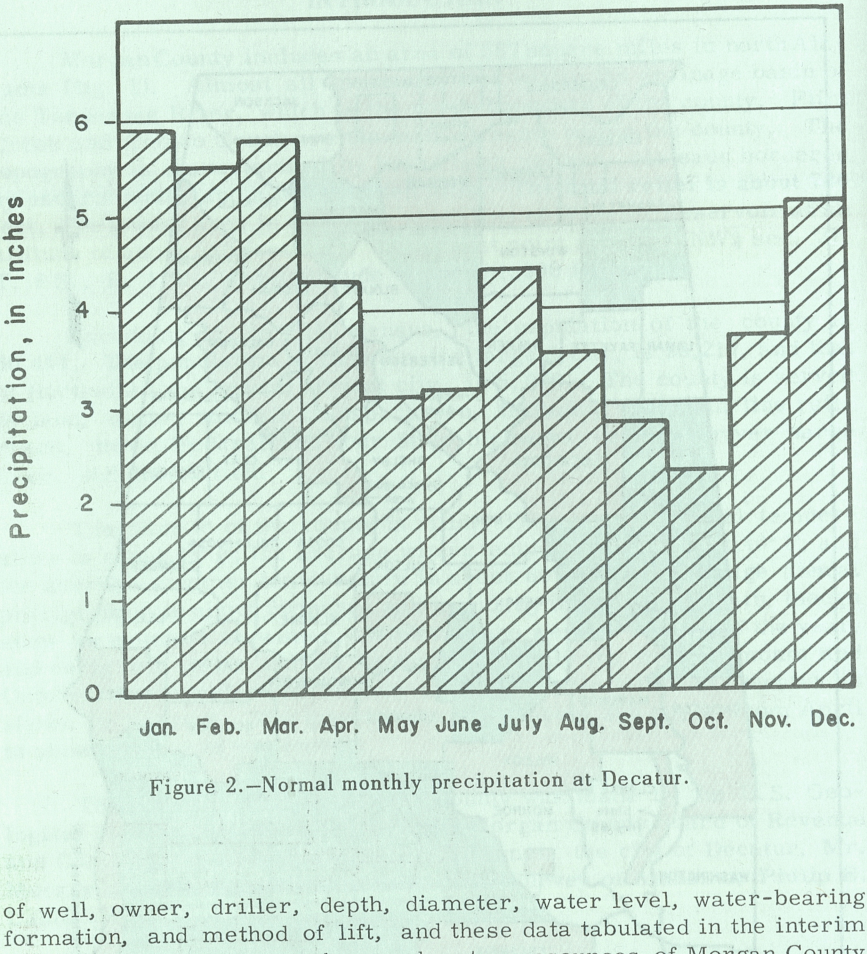


Figure 2.—Normal monthly precipitation at Decatur.

of well, owner, driller, depth, diameter, water level, water-bearing formation, and method of lift, and these data tabulated in the interim report on the geology and ground-water resources of Morgan County (Dodson and Harris, 1961, table 2). Water levels in 40 wells were recorded biweekly for periods ranging from 6 months to 3½ years, and water-level recorders were maintained on 12 wells for periods ranging from 1 month to 3 years. Water-level fluctuations in these wells were correlated with precipitation, changes in water level in Wheeler Reservoir, earthquakes, pumpage, and barometric changes.

As a part of the determination of the chemical character of the ground water in the county, more than 2,000 samples were collected during the well-inventory phase of the investigation and were analyzed for hardness and chloride content in the field laboratory (Dodson and Harris, 1961, table 2). A more complete analysis was made on 47 samples in the laboratory of the Quality of Water Branch of the Geological Survey at Ocala, Fla. The constituents determined included iron in solution, calcium, magnesium, sodium, bicarbonate, carbonate, sulfate, chloride, fluoride, nitrate, hardness, pH, and specific conductance; 13 samples were analyzed for fluoride, and 4 samples for total iron.

Twelve test wells were drilled in areas where additional geologic and hydrologic data were needed. Locations of these wells are shown in figure 3. Pumping tests were made on 10 of the wells to determine the hydraulic characteristics of the water-bearing formations and the quantity of water available. The results of bailing tests made on two wells indicated yields of less than 30 gpm during periods of low water levels.

The geology of the county was mapped to aid in the determination of its relation to the occurrence and movement of ground water. It was drawn on $7\frac{1}{2}$-minute topographic quadrangle maps and transferred to the base map at the publication scale of about 1 inch equals 1 mile (pl. 1). Because much of the county is covered by unconsolidated deposits, the bedrock contacts drawn on the map are generalized for many areas.

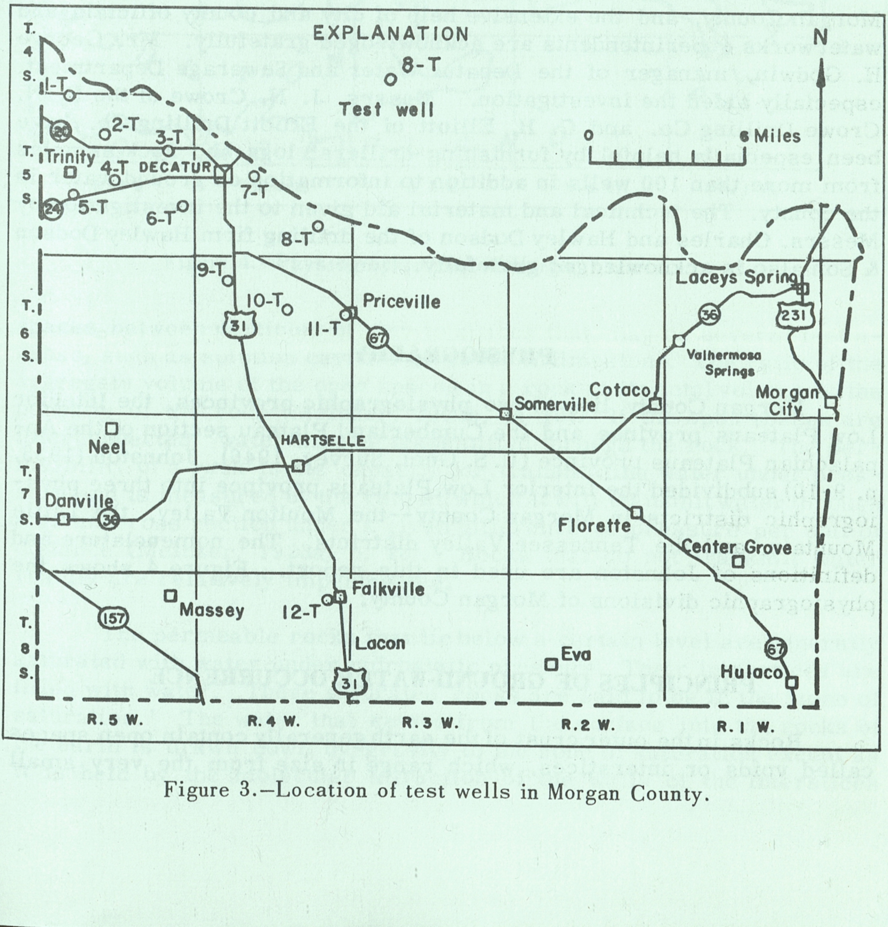

EXPLANATION
8-T
Test well
0
6 Miles
N
T. 4 S.
T. 5 S.
T. 6 S.
T. 7 S.
T. 8 S.
1-T
2-T
3-T
4-T
5-T
6-T
7-T
8-T
9-T
10-T
11-T
12-T
20
24
31
67
36
231
157
Trinity
DECATUR
Priceville
Laceys Spring
Valhermosa Springs
Cotaco
Morgan City
Somerville
Neel
HARTSELLE
Danville
Florette
Center Grove
Massey
Falkville
Lacon
Eva
Hulaco
R. 5 W.
R. 4 W.
R. 3 W.
R. 2 W.
R. 1 W.

Figure 3.–Location of test wells in Morgan County.

This report is divided into three main parts: the geologic formations and their water-bearing properties, the ground-water resources of the county, and the chemical quality of the water.

PREVIOUS INVESTIGATIONS

Several workers have included Morgan County as part of regional studies. Among them were Tuomey (1858), Smith (1890, 1894, 1907), McCalley (1896), Butts (1926), Semmes (1929), Johnston (1933), and Welch (1958). The report by Johnston (1933, pt. 1, p. 290-296; pt. 2, tables 35 and 36) outlined the geology, physiography, and occurrence of ground water in each of the formations and included water analyses from four wells and two springs.

ACKNOWLEDGMENTS

The information on wells and springs contributed by citizens of Morgan County, and the extensive help of city and county officials and waterworks superintendents are acknowledged gratefully. Mr. George H. Godwin, manager of the Decatur Water and Sewerage Department, especially aided the investigation. Messrs. J. N. Crowe of the H. N. Crowe Drilling Co. and C. H. Elliott of the Elliott Drilling Co. have been especially helpful by furnishing drillers' logs and rock samples from more than 100 wells in addition to information on ground water in the county. The technical and material aid given to the investigation by Messrs. Charles and Hawley Dodson of the drilling firm Hawley Dodson & Son also is acknowledged gratefully.

PHYSIOGRAPHY

Morgan County lies in two physiographic provinces, the Interior Low Plateaus province and the Cumberland Plateau section of the Appalachian Plateaus province (U. S. Geol. Survey, 1946). Johnston (1933, p. 9-10) subdivided the Interior Low Plateaus province into three physiographic districts in Morgan County--the Moulton Valley, the Little Mountain, and the Tennessee Valley districts. The nomenclature and definitions of Johnston are used in this report. Figure 4 shows the physiographic divisions of Morgan County.

PRINCIPLES OF GROUND-WATER OCCURRENCE

Rocks in the outer crust of the earth generally contain open spaces called voids or interstices, which range in size from the very small

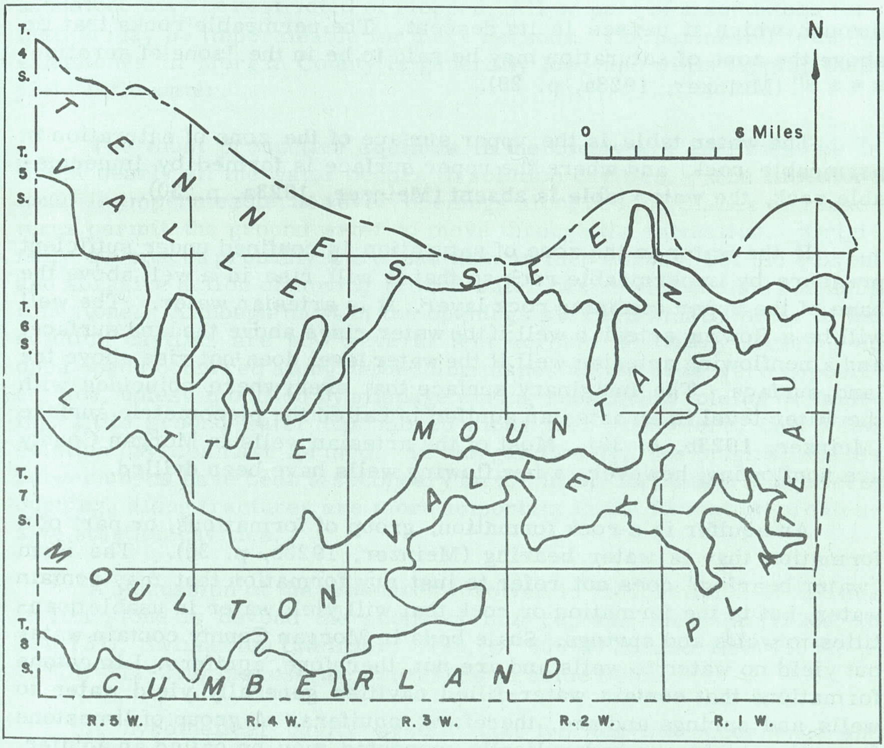


Figure 4.–Physiographic map of Morgan County.

spaces between particles of clay to spaces that may be several feet across, such as solution cavities or caves in limestone. The ratio of the aggregate volume of the open spaces in a rock to its total volume is the porosity of the rock (Meinzer, 1923b, p. 19). If the open spaces are interconnected, water may be transmitted through the rock. The permeability of a rock is its capacity for transmitting water under pressure and is measured by the rate at which it will transmit water through a given cross section under a given difference of pressure per unit of distance (Meinzer, 1923a, p. 28). Rocks that do not transmit water readily are relatively impermeable.

"The permeable rocks that lie below a certain level are generally saturated with water under hydrostatic pressure. Their interstices are filled with water. These saturated rocks are said to be in the 'zone of saturation.' The water that enters from the surface into the rocks of the earth is drawn down by gravity to the zone of saturation except as it is held by the molecular attraction of the walls of the interstices through which it passes in its descent. The permeable rocks that lie above the zone of saturation may be said to be in the 'zone of aeration' * * * *" (Meinzer, 1923a, p. 29).

The water table is the upper surface of the zone of saturation in permeable rock, and where the upper surface is formed by impermeable rock, the water table is absent (Meinzer, 1923a, p. 30).

If the water in the zone of saturation is confined under sufficient pressure by impermeable rock so that it will rise in a well above the base of the upper confining rock layer, it is artesian water. The well will be a flowing artesian well if the water rises above the land surface, and a nonflowing artesian well if the water level does not rise above the land surface. The imaginary surface that everywhere coincides with the water level in an artesian aquifer is called the piezometric surface (Meinzer, 1923b, p. 38). Most of the artesian wells in Morgan County are nonflowing; however, a few flowing wells have been drilled.

An aquifer is a rock formation, group of formations, or part of a formation that is water bearing (Meinzer, 1923b, p. 30). The term "water bearing" does not refer to just any formation that may contain water, but to the formation or rock that will yield water in usable quantities to wells and springs. Shale beds in Morgan County contain water but yield no water to wells and are not, therefore, aquifers. Limestone formations that contain water-filled cavities generally yield water to wells and springs and are, therefore, aquifers. A group of limestone formations that are hydraulically connected may be called an aquifer.

Ground water is that part of the subsurface water that is in the zone of saturation (Meinzer, 1923a, p. 38), and in Morgan County, ground water is derived from precipitation that is almost entirely rain; less than 5 percent of the precipitation is snow and ice. Part of the rainfall runs off into streams, and part of it evaporates. The rest seeps into the soil where it may be partly absorbed or may be used by vegetation. About one-fourth of the total precipitation in the county percolates downward through the soil and becomes ground water (Curtis, 1953, p. 36).

In Morgan County, ground water is obtained chiefly from limestone and sandstone, but also from dolomite, chert, and conglomerate. The surficial unconsolidated deposits of sand, gravel, and chert rubble also are water bearing, and some chert-rubble deposits contain large quantities of water. Sandstone contains ground water in the interstices between sand grains, in openings along bedding planes, and in fractures. If water can move freely in these open spaces, the sandstone is permeable and large quantities of water may be obtained from it, but if the interstices between sand grains are filled with cementing material and other open spaces are few or small, the movement of water through the sandstone may be restricted or stopped. All or part of a sandstone formation may be impermeable for these reasons. The permeability of the sandstones in Morgan County is generally low, and wells tapping them yield little water.

The most productive aquifers in the county are in limestone in which nearly all the water occurs in solution cavities. The limestone itself is impermeable; however, openings along bedding planes and fractures permit the ground water to move through the formation. Originally the spaces probably were less than an inch across, but the solvent and abrasive action of moving ground water has eroded the surrounding limestone. Although most of the openings still are small, some of the solution cavities are now several feet across. Probably little or no open space occurred along the bedding planes as the beds were deposited, and, unless modified by slippage during subsequent folding or faulting, little ground water has moved along them; therefore, only a few solution cavities have formed. In Morgan County, the original spaces between beds have been a secondary factor in the formation of aquifers; openings along fractures are more important in the formation of extensive solution cavities.

A discussion of the processes involved in the formation of cavities in limestone is beyond the scope of this report. Meinzer (1923a, p. 131-137), Swinnerton (Meinzer, 1942, p. 656-677), and Hem (1959, p. 70-78, 211-214) discuss the processes in some detail.

A hypothetical cavity system that typifies the occurrence and movement of ground water in the limestone aquifers of Morgan County is shown in figure 5. Although the diagram is idealized, some of the features, such as the fault and the cavity shapes, were drawn from actual outcrops in quarries, road cuts, and caves in the county. The path of only one hypothetical particle of water is shown, but all cavities and fractures below the water table would be in the zone of saturation and would be filled with water. Water would probably be moving in all the cavities and in most of the joints. Joints above the water table would transmit water to the cavity system. If the water were transmitted to the zone of saturation at a rate greater than the discharge from the cavity system, the water table would rise above the position shown, and if it were transmitted at a rate less than the discharge, the water table would be lowered, perhaps to a position where the upper cavity would be only partly filled.

GEOLOGIC FORMATIONS

In Morgan County, seven rock formations of Mississippian age and one of Pennsylvanian age contain the principal aquifers. Summary descriptions of the formations and their water-bearing properties are shown in table 1. The distribution of the outcrop areas of these bedrock

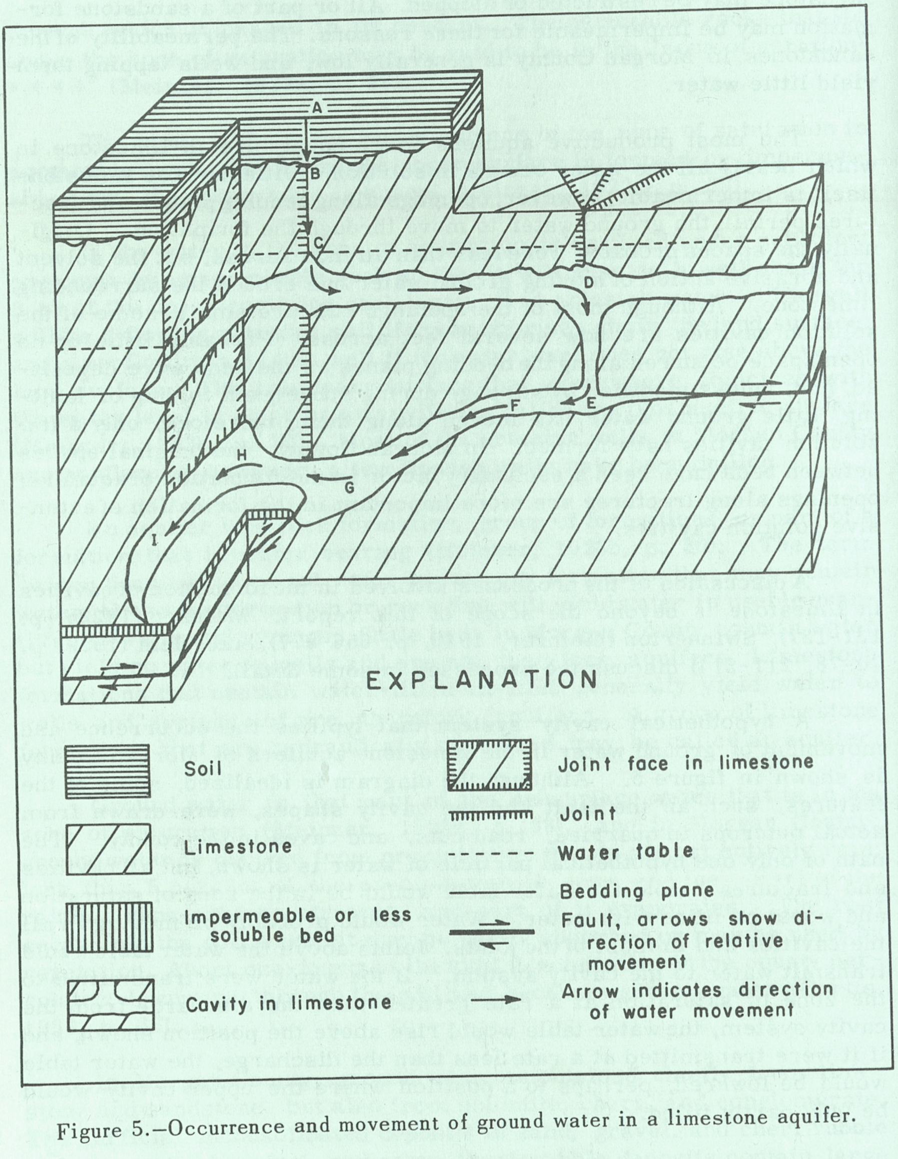

A
B
C
D
E
F
G
H
I
EXPLANATION
Soil
Limestone
Impermeable or less soluble bed
Cavity in limestone
Joint face in limestone
Joint
Water table
Bedding plane
Fault, arrows show direction of relative movement
Arrow indicates direction of water movement

Figure 5.–Occurrence and movement of ground water in a limestone aquifer.

Table 1.—*Generalized section of the Chattanooga Shale and younger geologic formations and their water-bearing properties*

Age	Formation	Thickness (feet)	Rock description	Water-bearing properties
Post-Pennsylvanian	Undifferentiated	0-100±	Clay weathered from shale.	Yields no water to wells.
			Clay, silt, sand, and gravel weathered from sandstone.	Yields some water to dug wells.
			Broken rock from collapsed Hartselle Sandstone.	May yield water to wells in a few small areas.
			Broken rock in probable collapse structures.	Yields more than 20 gpm (gallons per minute).
			Nodules and rubble of chert weathered from limestone.	Some wells developed in this material yield more than 20 gpm.
	Unconformity			
Pennsylvanian	Pottsville Formation	Less than 300	Sandstone, gray, very thin to thick-bedded, weathers yellowish brown; contains shale, siltstone, conglomerate, and coal.	Water occurs along bedding planes and in fractures; typical wells yield less than 10 gpm; water contains excessive iron.
	Unconformity			
Mississippian	Pennington Formation	70-150	Limestone, gray, very fine to coarse-grained, thin to very thick bedded, partly oolitic, partly argillaceous, interbedded with shale; red and green shale; light-gray dolomite.	Water occurs in the limestone in cavities and fractures; supplies many small springs; some springs yield more than 100 gpm; few wells yield as much as 10 gpm. The shale yields no water.
	Bangor Limestone	340	Limestone, gray, finely crystalline, very fine to coarse-grained, thin to very thick bedded, partly oolitic; contains shale and cherty and dolomitic limestone beds.	Water occurs in cavities and fractures; minimum flow from some springs is greater than 100 gpm; wells may yield 100 gpm.
	Hartselle Sandstone	5-120	Sandstone, gray, thin- to thick-bedded, calcareous, weathers yellowish brown; some parts at bottom are silicified; contains some shale beds.	Water occurs in fractures and along bedding planes; wells yield less than 10 gpm.
	Unconformity			
	Gasper Formation	90-110	Three distinct units: top and bottom limestone units, gray, thick-bedded, medium- to coarse-grained, clastic, partly oolitic and cherty, each about 30 ft thick; middle unit is gray shale about 40 ft thick.	Water occurs in cavities and fractures in the limestone; the shale yields no water; many springs issue from the top limestone, many of them yielding as much as 100 gpm; wells commonly yield more than 10 gpm; the bottom limestone unit yields less water.
	Ste. Genevieve Limestone	60	Limestone, light-gray, massive, thick-bedded, oolitic.	Water occurs in cavities and fractures, chiefly at or near contacts with overlying and underlying formations; yields little water except in and near its area of outcrop.
	Unconformity			
	Tuscumbia Limestone	180	Limestone, light-olive-gray to light-gray, fine- to coarse-grained, thick-bedded; contains nodules and interbeds of chert.	Water occurs in cavities and fractures; wells that are capable of yielding 100 gpm are common.
	Fort Payne Chert	210	Limestone, dolomitic limestone, dolomite, and chert, olive-gray and greenish-gray; contains some shale; does not crop out in Morgan County.	Water occurs in cavities and fractures; wells are capable of yielding more than 150 gpm; estimated maximum yield of one test well is 1,100 gpm.
	Unconformity			
Devonian	Chattanooga Shale	4-14	Shale, dark-brownish-gray, appears black when wet; contains thin sandstone beds at top and bottom; does not crop out in Morgan County.	Yields no water. Main confining bed in the county.

formations is shown on plate 1. The Fort Payne Chert, the oldest Mississippian formation, does not crop out in the county. The unconsolidated deposits, which cover the bedrock over more than three-fourths of the area of the county, are treated in this report as a single rock formation, designated post-Pennsylvanian undifferentiated. Locally, where these unconsolidated deposits are composed of residual sand or chert rubble, they may yield adequate supplies of water for domestic use. Only formations above the Chattanooga Shale, of Devonian age, can be expected to yield water suitable for ordinary uses. Although the Chattanooga yields little or no water to wells penetrating it, it forms an impermeable barrier to the downward movement of the water and is therefore important to the occurrence of ground water in the county.

The nomenclature and definitions of geologic formations used in this report are those used by Butts (1926). Welch (1958) placed the rock units occurring between the Tuscumbia Limestone and the Hartselle Sandstone into a new formation, the Pride Mountain Formation, but he was unable to recognize any of the several members of the Pride Mountain in Morgan County. Retaining the names of Gasper Formation and Ste. Genevieve Limestone, as used by Butts (1926), for rocks between the Hartselle and Tuscumbia is more appropriate for purposes of this study than using the name Pride Mountain Formation and is the acceptable nomenclature used by the Geological Survey of Alabama.

Terminology used to describe bedding in this report is that proposed by McKee and Weir (1953). The "Glossary of Geology and Related Sciences" of the American Geological Institute was used as the reference for definition of other geologic terms. The "Rock Color Chart" of the National Research Council was used as a reference in describing colors of rocks.

The aquifers are chiefly limestone. The bedrock above the Chattanooga Shale is about 60 percent limestone, 15 percent sandstone, 10 percent chert, 10 percent shale, and 5 percent dolomite. Two formations, the Pottsville Formation and the Hartselle Sandstone, are mostly sandstone, the Gasper Formation is about one-third shale, but all other formations are mostly limestone. Solution cavities in the limestone contain most of the ground water that can be developed in the county. The permeability of the sandstone is generally low, solution cavities do not readily form in the dolomite, and the chert and shale are impermeable; compared to the limestones, little water can be obtained from these rocks.

Plate 2 shows the geologic structure of Morgan County. The regional dip is south about 30 feet per mile, but the normal dip is disrupted locally by broad folds. The structural features of the county are discussed in the sections on the geologic formations and on the structural control of ground water.

CHATTANOOGA SHALE

DESCRIPTION.—The Chattanooga Shale of Devonian age is not an aquifer in Morgan County. However, the formation, being impermeable, confines the circulation of ground water to the formations above. So far as is known, water below the Chattanooga is highly mineralized and unsuitable for domestic, stock, and most other uses; therefore, the formation lies at the greatest depth to which it is practical to drill water wells in the county. The formation is the marker bed that was used to prepare the structure map (pl. 2).

The Chattanooga Shale is classified as a black shale formation, but dark-brownish-gray fissile shale and two thin beds of yellowish- or greenish-gray poorly sorted fine-grained calcite-cemented sandstone generally compose the formation in Morgan County, and pyrite is characteristically abundant. The beds of sandstone, each about half a foot thick, generally are at the top and bottom of the formation; however, in test wells 5-T and 6-T more than half the Chattanooga is composed of sandstone (table 5). The thickness of the Chattanooga penetrated in test wells ranges from 4 to 14 feet. The contact between the Chattanooga and the Fort Payne Chert is an unconformity.

GROUND WATER.—The Chattanooga is not an aquifer; however, water in contact with the Chattanooga generally is mineralized. Hydrogen sulfide escapes into the water in wells tapping the formation and causes the water to become sulfurous. If the amount of mineralized or sulfurous water is undesirable, the Chattanooga is sealed off before completion of the well.

FORT PAYNE CHERT

DESCRIPTION.—The Fort Payne Chert, the oldest formation of Mississippian age that underlies Morgan County, does not crop out in the county and is everywhere at a depth greater than 40 feet below the land surface. All rocks between the Chattanooga Shale and the Tuscumbia Limestone are included in the Fort Payne Chert for the purpose of this report. The average thickness of the Fort Payne in test wells drilled in Morgan County is about 210 feet. The formation is not chert, as its name implies, but limestone, dolomite, chert, and shale. Its average composition as determined from drill cuttings in 10 test wells is about 50 percent limestone and dolomitic limestone, 25 percent dolomite, 20 percent chert, and 5 percent shale. Most of the limestone and dolomite is very fine grained. Very fine grains of silica occur in much of these rocks and are abundant in places. The limestone, dolomite, and silica were probably deposited by chemical precipitation.

The lithology of the Fort Payne is so varied that no simple description is appropriate. The complexity of the lithology and stratigraphy can be seen in the logs of the test wells (table 5). The Fort Payne comprises three main units. The lower unit is generally composed of greenish-gray very fine grained, partly silicified, partly calcareous dolomite and bluish-gray and greenish-gray chert. Downward from the top of the unit, the grain size of the dolomite generally decreases and the dolomite becomes increasingly argillaceous. Locally, the lower unit contains gray, greenish-gray, and olive-gray very fine grained dolomitic limestone. Nearly half the lower unit in test well 7-T is composed of limestone, but limestone is a minor constituent in the other test wells. A light-greenish-gray shale about half a foot thick that occurs at the base of the Fort Payne has been included in the lower unit.

Drill cuttings indicate that the lower unit is laminated to very thin bedded and contains a few shale laminae and thin beds of greenish-gray and gray shale. The shale content of the unit, as seen in cuttings from test wells, generally increases northwestward. The shale is a minor constituent in test well 9-T, less than 2 percent, but the bottom half of the unit in well 4-T is about 5 percent dark-gray shale, and the unit in well 1-T is about 10 percent dark-greenish-gray shale.

Crinoid stem plates up to half an inch in diameter are locally abundant in the lower unit, and stem plates, other crinoidal debris, and bluish-gray chert may compose an extraordinary limestone unit. In well 7-T, this limestone unit is 5 feet thick and lies about a foot above the base of the Fort Payne, but a similar bed in well 10-T is 17 feet thick, contains little chert, and is 55 feet above the base of the formation. In well 10-T, the abundance of crinoid stem plates gradually decreases both upward and downward from the crinoidal limestone unit. The crinoid stem plates are calcite, but, of those plates that are surrounded by a matrix of chert or dolomite, about 1 mm of the outer rim is replaced by the matrix material.

The middle unit of the Fort Payne is chiefly light-olive-gray very fine grained, partly silicified dolomitic limestone, light-olive-gray to light-greenish-gray very fine grained, partly silicified dolomite, and light-bluish-gray and very light olive-gray to very light greenish-gray chert. The olive-gray and greenish-gray chert is the product of complete silicification of limestone or dolomite. The very fine grained structure of the limestone and dolomite was not altered in silicification. A study of cuttings from test wells in the county indicates that the average composition of the middle unit is about one-third chert.

The upper unit is composed mainly of very light olive-gray fine- to coarse-grained clastic limestone, light-olive-gray fine-grained, partly dolomitic and partly siliceous limestone, light-olive-gray very fine grained calcareous dolomite, and bluish-gray chert. The lithology of the clastic limestone is the same as that of the overlying Tuscumbia

Limestone. The upper unit comprises tongues of Tuscumbia and tongues of Fort Payne, and the very fine grained chemically precipitated limestone or dolomite differentiates this unit from the Tuscumbia. The Tuscumbia is a facies of clastic deposition, and the Fort Payne is a facies of chemical deposition. Lithologies of the two facies do not appear to be gradational. The contact between the Tuscumbia Limestone and the Fort Payne Chert has been drawn at the top of the uppermost tongue of olive-gray very fine grained dolomitic limestone, or dolomite, and bluish-gray chert. The upper unit is identified in all test wells except 9-T, where the chert, ordinarily the most conspicuous constituent, is absent; however, the curve that is typical at the Fort Payne-Tuscumbia contact appeared on the electric log of 9-T. The curve was approximately the same at the contact as the curve shown on plate 4. If the contact were drawn at the bottom of the lowermost light-olive-gray fine to very coarse grained oolitic clastic limestone, which is the lowermost tongue of the Tuscumbia, the contact in some wells would be as much as 100 feet lower than where it is drawn. The contact was chosen at the top of the highest Fort Payne tongue, chiefly because this choice includes in the upper unit all the Fort Payne lithology of uniform thickness.

The three units of the Fort Payne are gradational. The colors gradually become lighter upward and grade from green to olive (yellowish). From about the center of the lower unit, the content of bluish-gray chert generally increases downward to the bottom of the Fort Payne and upward into the middle unit. The amount of clastic limestone generally increases upward from the base of the upper unit, as the amount of chemically deposited limestone and dolomite decreases. From near the bottom of the formation upward the dolomite content decreases, as does the content of very fine grains of silica. The thickness of the bedding probably increases upward also; at least part of the bedding in the lower unit is laminated, and some of the clastic limestone in the top unit is probably thick bedded.

An odd characteristic of part of the chert in the Fort Payne can be used to distinguish the formation from the Tuscumbia Limestone. Cuttings of the chert fresh from the well are blue. The colors range from very light blue to light blue, but they rapidly change to grayish blue, then to bluish gray or white. The change from blue to grayish blue occurs within 5 minutes after the sample is bailed from the well, and the change to bluish gray generally occurs by the time the washed sample is dry. The change is probably caused by oxidation, and the rapidity of the change limits the usefulness of the characteristic.

The greenish fine-grained rock in the lower unit, when fresh from the well, is grayish green, but the color becomes lighter and more gray with time, a color change similar to that in the bluish-gray chert. The shale cuttings probably become brown with time. McGlamery (1955,

p. 348-363) recorded much more brown than was observed in the samples collected during this study. The green is probably due to reduced iron, which oxidizes to brown on exposure to the air.

GROUND WATER.—Only a few wells penetrate the Fort Payne Chert in Morgan County, and data available for use in preparing this report are chiefly from 11 test wells drilled as part of the study (table 2). Fractured zones and solution cavities are the main sources of water in the formation. Most of the water-bearing open spaces are so small that they are hardly noticed in drilling, the openings being detected only by a change in the consistency of the mud in the bottom of the well. Individual solution cavities more than 2 inches thick are not common; these small cavities may occur in groups, in what could be termed "cavity zones." The zones of both fractures and cavities are ordinarily $\frac{1}{2}$ to 1 foot thick; however, a cavity zone 13 feet thick was penetrated in well 5-T, and 7 large open cavities were penetrated in well 8-T, a total of 24 feet of cavity in 85 feet. Almost all the rock cut in this well was broken or brecciated. An open cavity, 4 feet thick, was penetrated in well 2-T and a filled cavity, 1 foot thick, was cut in well 7-T; none of the other test wells contained a large cavity. Many of the cavities are filled or partly filled with mud, silt, sand, gravel, or breccia. The cavity in well 7-T is filled with small, well-rounded pebbles of dolomite cemented by elongated crystals of calcite that are about 1 mm in diameter.

One explanation of the large number and size of cavities in the Fort Payne in test well 8-T is that it is in the possible collapse structure discussed in the section on unconsolidated deposits. Another explanation is that the well penetrates a fault zone, although no extensive high-angle fault has been recognized in the county. Chert breccia recemented by pyrite was obtained from the well between depths of 235 and 290 feet, where no cavities occur and where no solution of the rock is apparent.

The deep fractured zones in the Fort Payne are probably thrust fault zones, and the cavity in well 7-T probably formed along a fault. Brecciated rock was obtained from several of the test wells, from zones that probably are horizontal. If the breccia were from joints, the zones would appear thicker than they ordinarily do, and the drill would be deflected at the bottom.

The Fort Payne Chert and the overlying Tuscumbia Limestone are effectively a single aquifer, as no confining bed separates the two formations. Recharge generally moves downward to the Fort Payne from the Tuscumbia. The water-bearing properties of the two formations differ, as do the properties of the three units in the Fort Payne, but regionally they are considered as one aquifer.

Table 2.—*Records of test wells in Morgan County, Ala.*

Water-bearing formations: Mfp, Fort Payne Chert; Mt, Tuscumbia Limestone; Mb, Bangor Limestone.

Well	Property owner	Altitude of land surface (feet)	Depth of well (feet)	Depth of $6\frac{1}{4}$-inch casing (feet)	Water-bearing formation	Depth to top of Chattanooga Shale (feet)	Water-bearing zones		Temperature (° F)	Pumping tests					Remarks
							Depth (feet)	Thickness (feet)		Date of test	Rate of discharge (gpm)	Duration of pumping (hours)	Drawdown observed during test (feet)	Specific capacity (gpm per foot of drawdown)	
1-T	John B. Sewell.	568	276.8	84	Mfp	271	130 133	3 2	62	7-14-60	117 233 350	4 4 16	6.3 19 35.6	19 12 10	See fig. 14.
2-T	Louie and Paul Glenn	592	356.0	48	Mfp	343	151 1/212	2 4	62	11-15-60	275	24	80	3	
3-T	City of Decatur and Fruehauf Trailer Co.	584	251.0	40	Mfp	246	89 179	.5 1	62	3- 4-58	102	24	52	2	
4-T	Louhoward Bouldin. . .	606	340.5	40	Mt	329	50 60	.5 .5	63	2-27-61	205	24	30	7	
5-T	George H. Burt	665	439.5	33	Mt-Mfp	421	102 163 231 396	1 1 13 1	62	12-22-59	90	24	76	1	See fig. 8.
6-T	Rolan Royer	610	305.6	26	Mt	299	45 116 148	. . . .	. . . . . .	. . . .	. . . .	. . . . . .	. . . .	. . . . . .	
7-T	City of Decatur	570	294.8	23	Mfp	286	241	1	64	7-23-59	55	1	134	. .	
8-T	U.S. Dept. Interior Fish and Wildlife Service.	624	301.2	148	Mfp	293	1/151 1/159 1/193 230	4 5 2 .5	62	7-11-60	108 250 350	4 4 16	4.5 15.3 25	24 16 14	See figs. 9 and 15.
9-T	Jay J. McMurray	565	382.7	21	Mt-Mfp	370	72 293 300 337	. . . 1	64	11-24-59	100	24	22	4	
10-T	Enoch Poole	566	361.9	41	Mt	344	48.5	. . .	62	. . . . . .	. . .	. .	. . .	. .	
11-T	Morgan County Dept. of Education.	625	355.8	53	Mt-Mfp	. . .	1/ 62 1/121 1/224 343	1 .5 4	62	5- 3-61	200 to 250	24	60 to 75	3	
12-T	Morgan County, Falkville Road Shop.	592	132.7	14	Mb	. . .	29 75	1 5	62	6- 8-61	33	.5	27	. .	

1/ Open crevice

In the test wells, generally, the greatest yield was from the upper unit of the Fort Payne Chert; the yield from the middle unit was intermediate, but only small quantities of water were obtained from the lower unit.

Tongues of the fine-grained dolomitic limestone and calcareous dolomite and chert may effectively control the occurrence of ground water in the upper unit of the Fort Payne. Because these tongues are less soluble than the coarser grained clastic limestone, they could act as confining beds not only in creating artesian conditions but also in creating barriers to the lateral movement of ground water into some areas. All other factors being equal, the abundance of ground water in the Fort Payne would decrease with an increase in fine-grained rock in the upper unit.

Several reasons may account for the lack of ground water in the lower unit. The main reason is that the dolomite or dolomitic limestone is nearly insoluble, so that if solution openings formed at all they would tend to be small. In the laminated or thin-bedded rock, strain would be relieved along bedding planes, and no large open fractures would form. All or most of the carbon dioxide from the atmosphere and soil would be neutralized before the water reached the depths of the lower unit, and circulation ordinarily is not great at these depths; therefore, solution of even the more soluble parts of the unit is likely to be minimized. The basal part of the lower unit of the Fort Payne is generally an effective barrier to the movement of ground water, probably as effective as the Chattanooga Shale.

Only 17 wells are known to have been drilled into the Fort Payne Chert in Morgan County, excluding oil-test holes and Geological Survey test wells. Most of these wells are no deeper than the uppermost water-bearing zone in the Fort Payne.

Estimated yields from test wells tapping the Fort Payne range from less than 10 to 1,100 gpm; most of the wells would yield more than 150 gpm. The estimate of 1, 100 gpm from well 8-T is probably low because the well is cased to a depth of 148 feet, and cavities totaling 12 feet in thickness were cased off to prevent caving. The cavity between the depths of 120 and 125 feet is free of sediment and contains clear water. Sand and rubble in the cavity at 139 to 144 feet interfered with drilling to such an extent that this interval was cased off, but the cavity could be cleaned out in a well with a diameter larger than 6 inches. Test well 8-T is perhaps anomalous, for little brecciation has been recognized in other test wells; however, the collapse structure extends about a mile southwest of the test well and covers between 0. 2 and 0. 7 square mile. The area affords a possible site for development of large quantities of ground water.

The rate of discharge given in table 2 for well 7-T is 55 gpm with a drawdown in water level of 134 feet below the land surface, but the well probably would yield more water after complete development to clear the dolomite pebbles and calcite cement from the cavity.

The Fort Payne Chert can be expected to yield quantities of water from other wells drilled in the Tennessee Valley in Morgan County comparable to the quantities developed from test wells 1-T through 11-T. In other areas of the county, yields would be much less.

Because the lower unit of the Fort Payne yields little water, wells ordinarily could be stopped at the top of this unit rather than at the Chattanooga Shale. Identification of the top of the unit is more difficult than identification of the Chattanooga, however, and if a well were stopped too high, water in the middle unit of the Fort Payne might be missed. The lower unit of the Fort Payne can be easily identified by use of electric logs. The electric log is characterized by a decrease in the resistivity curve and a positive deflection in the self-potential curve (pl. 4).

TUSCUMBIA LIMESTONE

DESCRIPTION.– The Tuscumbia Limestone is the oldest formation that crops out in Morgan County. It comprises two formations, the St. Louis Limestone and the Warsaw Limestone, but because the St. Louis and Warsaw are lithologically similar and are defined chiefly on paleontological evidence in this area, they have been combined into the one unit (Butts, 1926, p. 167-177). The area of outcrop of the Tuscumbia covers about 75 square miles of the Tennessee Valley physiographic district (pl. 1). The lower 40 feet of the formation does not crop out in Morgan County. The Tuscumbia is about 180 feet thick and is composed mainly of very light gray to light-olive-gray fine- to coarse-grained clastic thick-bedded to very thick bedded limestone, and contains nodules of bluish-gray chert. Limestone in the Tuscumbia is generally composed of grains of fossil debris and oolites. The relationship of the Tuscumbia and Fort Payne is discussed in the preceding section.

The Trinity quarry, in the SW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 8, T. 5 S., R. 5 W., is the only place known in Morgan County where the contact of the Tuscumbia with the overlying Ste. Genevieve Limestone can be carefully examined. At this locality it appears to be conformable; however, it is probably an unconformity (Butts, 1926, p. 177; Welch, 1958).

The section of the Tuscumbia Limestone exposed in Trinity quarry is as follows:

	Thickness (feet)
Ste. Genevieve Limestone:	
Limestone, light-olive-gray to yellowish-white, medium to very coarse grained, oolitic and fossiliferous, very thick bedded.	38
Tuscumbia Limestone:	
Limestone, medium to light-olive-gray, very fine grained and finely crystalline, laminated to very thin bedded, clayey, silty	12
Chert, pale-yellowish-brown and very pale orange, very fine grained or finely crystalline, intraformational breccia	2
Chert and limestone, pale to very pale orange, about 50 percent calcite fossil debris of sand size and 50 percent chemically deposited silica	9
Limestone, light-olive-gray, fine to very coarse grained, crystalline.	1

Chert rubble from the chert beds is conspicuous on the land surface in parts of the outcrop area of the Tuscumbia. The chert beds are the source of the specimens of *Lithostrotionella castelnaui* in the soil in Decatur. This fossil, *L. castelnaui*, or *Lithostrotion canadense* as called by Butts (1926, p. 173), is an index fossil of the St. Louis Limestone.

GROUND WATER.—The water-bearing properties of the Tuscumbia Limestone are similar to the ground-water properties of the Fort Payne Chert, and the two formations are considered as one aquifer. Extensive cavity systems have formed in the Tuscumbia, but individual cavities generally are no more than a foot thick, and a cavity as much as 5 feet thick is rare.

The Tuscumbia Limestone yields more water than any other formation in Morgan County. The water is obtained from about 1,000 wells and springs, and is used for domestic and stock supplies. In 1960 the total withdrawal was nearly 200,000 gpd (gallons per day), the average withdrawal per well being a little less than 200 gpd. Data are not available upon which to base an estimate of the maximum sustained yield of all wells in the Tuscumbia during times of drought, but if the yield were only 10 gpm per well, the wells tapping the Tuscumbia would yield 15 mgd (million gallons per day). The yield is undoubtedly much greater, because the average of the estimated yield during times of low water levels in test wells 4-T, 6-T, and 10-T, which obtain water from the Tuscumbia, is about 80 gpm, and yields of wells 5-T, 9-T, and 11-T from the Tuscumbia are probably greater. Wells that are capable of yielding 100 gpm or more are common. It is estimated that no more than 1 percent of the supply of ground water that can be obtained from the Tuscumbia Limestone in Morgan County was being used in 1960.

A well drilled in the outcrop area of the Tuscumbia ordinarily yields a supply of water at least adequate for domestic use; however, wells drilled in a few isolated hills where the formation is drained yield little or no water. The quantity of water that can be obtained from the formation generally decreases downdip, but supplies adequate for domestic use can be expected at least as far downdip as the surface contact of the Hartselle Sandstone and Gasper Formation (pl. 1). A few wells in the areas of outcrop of the Hartselle Sandstone and Gasper Formation in the Laceys Spring area probably would yield more than 100 gpm from near the top of the Tuscumbia or at the Ste. Genevieve Limestone-Tuscumbia contact. The sulfur and mineral content of the water tends to increase downdip beyond the Hartselle-Gasper contact, and water of satisfactory quality is not likely to be obtained from the Tuscumbia more than 2 miles downdip from its area of outcrop.

Several dug wells in the area of outcrop of the Tuscumbia yield larger quantities of water than are ordinarily expected from dug wells, but they probably penetrate cavities near the top of the bedrock. For example, the dug well at the Decatur Country Club in the NE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 32, T. 5 S., R. 4 W. (Dodson and Harris, 1961, table 2, C-19) was test pumped on April 3, 1958, at 130 gpm for 6 hours with a drawdown in water level of 3.5 feet, and during the period of low water level in the fall of 1959 the well is estimated to have been pumped at 200 gpm about 12 hours per day for about a month.

Many wells and springs in the county yield water from the cavity systems under the chert at the top of the Tuscumbia. The cavity that is cased off in well 9-T between depths of 12 and 20 feet formed below the chert bed. Clark Spring in the NE$\frac{1}{4}$SE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 36, T. 5 S., R. 5 W., yields water from the zone below the chert bed. The owner, P. H. Clark, stated that the average flow of the spring was about 200 gpm and the maximum flow was more than 600 gpm before the cavity system supplying the spring was tapped by shallow wells. The spring now flows only during times of highest water levels. About 3,000 gpm is pumped from wells in the area to supply fishponds; however, the ponds leak, so that part of the water is being recirculated. Cave Spring (pl. 3) issues from the zone below the chert bed and the yield ranged from an estimated flow of 100 gpm on October 24, 1958, to a measured flow of 4,100 gpm on April 13, 1960. Wheeler Reservoir covers Blue Spring in the

NW$\frac{1}{4}$NE$\frac{1}{4}$ sec. 4, T. 6 S., R. 4 W., and other springs in secs. 10 and 11, which probably flowed from the same zone.

STE. GENEVIEVE LIMESTONE

DESCRIPTION.—The Ste. Genevieve Limestone crops out in a narrow belt across the northern third of Morgan County in an area of about 45 square miles (pl. 1). The area of outcrop is in the Tennessee Valley physiographic district (fig. 4). The thickness of the Ste. Genevieve generally ranges from 40 to 65 feet and averages about 60 feet. The lower two-thirds of the formation is composed of massive thick-bedded light-gray oolitic limestone, and the upper third of the formation is composed of light- to dark-gray laminated to thick-bedded shale, chert, and limestone.

In the western part of Morgan County, the unit of very thick bedded limestone is overlain by a unit of laminated to very thin bedded medium-gray shale and limestone, which includes some chert. This shale and limestone unit is 12 feet thick in Trinity quarry and is ordinarily more than half shale. However, changes in the lithology of this unit were observed as quarrying progressed. In places, shale beds in the unit are as much as 4 feet thick. The chert content increases eastward, and in northeastern Morgan County the most prominent part of the unit is about 3 feet of chert at its base. This unit is referred to as the "shale unit" in this report. Very thin bedded to thick-bedded very fine to very coarse grained partly crossbedded partly oolitic limestone that is 5 to 20 feet thick overlies the shale unit.

The Ste. Genevieve Limestone contains, among other fossils, the distinctive stem segments and base plates of the crinoid *Platycrinites penicillus* Meek and Worthen. This fossil, where present, was used to differentiate the Ste. Genevieve and the overlying Gasper Formation. Where the fossil was not present, the uppermost shale bed in the Ste. Genevieve was used to locate approximately the contact.

Possibly the Ste. Genevieve is gradational with the Gasper Formation. Part of the Ste. Genevieve, as now defined, may belong in the Gasper Formation. The shale unit occurs 5 to 20 feet below the top of the uppermost *Platycrinites*-bearing bed; but above the shale unit the *Platycrinites* fossils are well rounded, and the spines on many of the stem plates are partly or completely worn away. Below the shale unit, most of these fossils are intact.

The basal contact of the Ste. Genevieve is discussed in the section on the underlying Tuscumbia Limestone.

GROUND WATER.— The Ste. Genevieve Limestone generally yields ground water chiefly from small openings along contact zones in quantities adequate for domestic use. Jointing in the very thick bedded limestone is widely spaced, so that only a few cavities have formed. The shale unit restricts the downward movement of water to the underlying limestone unit. In the western two-fifths of the area of outcrop, in the northeastern part of the county, and in a few scattered smaller areas where the shale unit has been removed by erosion, and where the formation is under rather deep soil cover, water can percolate downward along joints into the lower limestone unit. If the top unit of the Tuscumbia Limestone is impermeable or nearly so, as it is in places, the water tends to move laterally into solution cavities along the contact zone. Cavities also occur along the Gasper-Ste. Genevieve contact, in the Ste. Genevieve along the top of the limestone below the shale unit, and to a lesser extent in the oolitic limestone above the shale unit.

Thrust faulting was perhaps the most significant factor in the formation of cavities at or near the top of the Ste. Genevieve Limestone in some areas. In the Trinity quarry, a low-angle thrust fault is exposed between the shale unit and the top of the Ste. Genevieve. The fault surfaces ordinarily are coated with asphalt and pyrite, and near the fault some of the coarse-grained or coarsely crystalline limestone is impregnated with asphalt. Below the water table, the fault zone and the solution cavities formed along the fault would be filled with ground water. The extent of the faulting is not known, for the only good exposure is in Trinity quarry. Slickensides were observed in the outcrop along the county line west of Trinity and in a quarry in Trinity (pl. 1). No slickensides were found at the quarry in the NW$\frac{1}{4}$ sec. 19, T. 5 S., R. 5 W., or at the quarry in the SW$\frac{1}{4}$ sec. 35, T. 6 S., R. 5 W. The top of the shale zone is at or near the land surface at both these inactive quarries, and, if the fault is present, the slickensides have been obscured by weathering. It has not been possible to determine the extent of the fault because of the rarity of unweathered exposures.

From the Gasper-Ste. Genevieve contact to a mile or so beyond and under the shale in the Gasper Formation, small quantities of water may be obtained from openings along the upper contact zone.

GASPER FORMATION

DESCRIPTION.—The Gasper Formation crops out in an area of about 70 square miles in Morgan County (pl. 1). The thickness of the Gasper generally ranges from 90 to 110 feet, but local variation in thickness may be greater than 20 feet. For example, the formation is 120 feet thick along the Lawrence County line west of Trinity, but 1.5 miles away, along Alabama Highway 24 south of Trinity, it is 98 feet thick. Differences in thickness are caused mainly by relief on the unconformity at the top of the formation and differences in thickness of the shale unit in the middle of the formation. The upper and lower parts of the Gasper Formation in Morgan County are composed of limestone and are separated by shale. The limestones in the Gasper are ordinarily about 30 feet thick and are medium gray, thick-bedded, medium- to coarse-grained, clastic, and in part cherty and oolitic. The shale is generally about 40 feet thick and is medium gray, soft, and calcareous, and in places contains thin beds or lenses of gray limestone. The lithology of the Gasper is not uniform in Morgan County; for example, in the western part the formation is composed of as much as 60 percent shale, and in parts of the northeast corner of the county the formation is composed of as much as 90 percent limestone.

The Gasper Formation is unconformably overlain by the Hartselle Sandstone, as part of the Gasper was eroded and redeposited at the base of the Hartselle. This contact is discussed in detail in the section on the Hartselle Sandstone.

GROUND WATER.—Ground water in the Gasper Formation occurs in solution openings in the limestone. These openings are extensive and best developed at the contact of the Hartselle Sandstone and the Gasper, and at the contact of the upper limestone and the underlying shale. Solution cavities developed at the top of the Gasper may extend into the basal conglomeratic limestone of the Hartselle Sandstone. Water in the cavities is confined by sandstone or shale in the Hartselle Sandstone and by the shale in the middle part of the Gasper. A few wells tapping these cavities in the western part of Morgan County flow (Dodson and Harris, 1961, wells N-4, N-6, and N-9). Along the escarpment in the northern part of Morgan County are several hundred springs that flow from cavities in the limestone in the upper part of the Gasper. Discharges of many of these springs range from 10 gpm during periods of low water level to 100 gpm during periods of high water level. Shumake Park Spring (Dodson and Harris, 1961, spring M-232), flowing from a tubular opening in the limestone bed in the upper part of the Gasper, had an estimated flow of 100 gpm on February 26, 1959, and an estimated flow of 75-100 gpm during the fall of 1959.

In many areas of Morgan County the upper limestone bed of the Gasper has been removed by solution, and the overlying Hartselle Sandstone has collapsed onto the shale bed of the Gasper. This collapse feature is exposed in road cuts along Alabama Highway 24 south of Trinity, along U.S. Highway 31 between Flint and Hartselle, and at Flint (fig. 6). The collapse of the sandstone in the Hartselle has broken the sandstone mass, thus increasing its permeability and forming recharge areas for the upper part of the limestone in the Gasper.

The shale unit in the Gasper Formation in Morgan County is the first persistent confining bed above the Chattanooga Shale. It forms an effective barrier to the downward percolation of ground water, except in parts of the northeast corner of the county where it is thin and is

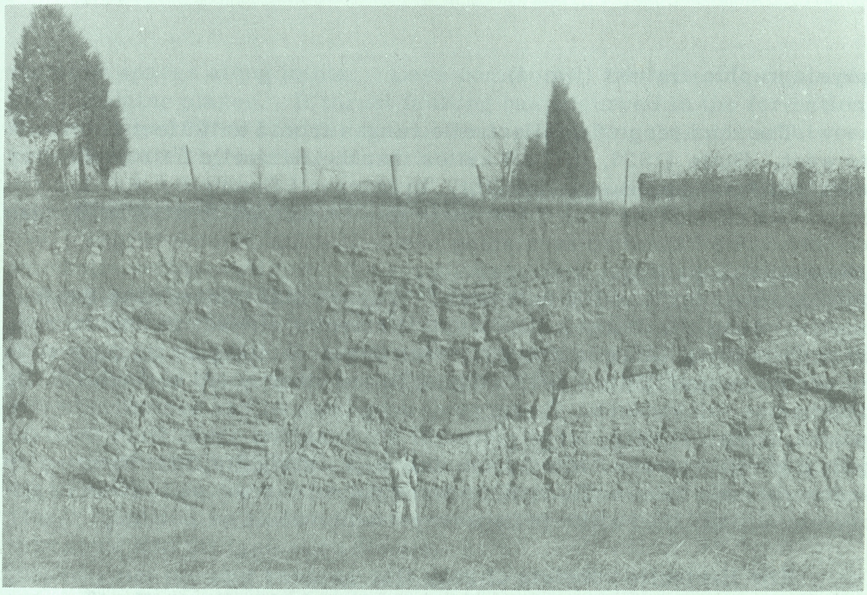


Figure 6.—Collapse of Hartselle Sandstone onto shale in the Gasper Formation along U.S. Highway 31 at Flint, Ala. Photograph facing east, taken by George W. Swindel, Jr.

composed of limestone interbedded with shale. These limestone beds do not yield water to wells penetrating them.

The lower limestone unit in the Gasper is not a productive aquifer in Morgan County.

In the areas of outcrop of the Gasper Formation and the Hartselle Sandstone, wells that tap the upper limestone in the Gasper generally yield 10 to 100 gpm of water of satisfactory quality for domestic and stock use. Downdip beyond the Hartselle outcrop area, almost all water in the upper limestone is in thin tabular cavity systems immediately underlying the Hartselle, and water supplies from the Gasper are inadequate.

HARTSELLE SANDSTONE

DESCRIPTION.—Smith (1894) named the Hartselle Sandstone for exposures at Hartselle in Morgan County. The Hartselle caps the low escarpment that extends from near Trinity to Hartselle and to the northeast corner of the county near Laceys Spring. The area of outcrop of the Hartselle in the county covers about 90 square miles (pl. 1). Sandstones in the Hartselle are more resistant to erosion than the underlying and overlying limestone formations; the sandstones form the escarpment and the small plateau that characterize the Little Mountain physiographic district (fig. 4).

The thickness of the Hartselle ranges from 5 to 120 feet from east to west. Butts (1926, p. 193) states that the Hartselle "* * * abruptly dies out * * * just east of the line, in Marshall County * * *," but the Hartselle is not less than 5 feet thick in all outcrops visited in Morgan County. The formation is missing in a well drilled in the NE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 16, T. 7 S., R. 2 W., but in another well 1.5 miles northeast, in the SE cor. sec. 3, it is 100 feet thick. The normal thickness of the formation along the Bangor Limestone-Hartselle contact in the outcrop area near these wells is about 45 feet. Thrust faulting or nondeposition in one place and fill of a deep channel in the other could account for the anomalous thicknesses. No narrow, deep channel has been found elsewhere; however, many large pieces of slickensided shale from the Gasper Formation were bailed from the well in section 16. Faulting in outcrops near these wells was not in evidence, but the soil cover is extensive in this area and a fault zone probably would be covered.

The Hartselle consists of gray fine-grained thin- to thick-bedded partly massive crossbedded quartzose silty, well-cemented calcareous sandstone, and a few beds of silty or sandy shale and siltstone. Commonly, near the bottom the formation contains interbedded, very thin bedded or laminated gray sandstone, siltstone, and shale, which is about 10 feet thick. Colors of the rocks are various shades of gray, chiefly greenish olive or bluish gray. The formation weathers yellowish brown.

The bottom bed of the Hartselle is ordinarily a basal conglomeratic limestone that contains limestone pebbles and fossil debris from the underlying Gasper Formation, but the lowermost bed may be sandstone, shale, or clastic limestone. The clastic limestone is conglomeratic in places; the pebbles are rounded pieces of fossils. The basal part of the lowermost sandstone bed in the Hartselle is commonly silicified. The silicified sandstone, or quartzite, generally ranges in thickness from 0.5 to 1 foot.

The Hartselle Sandstone unconformably overlies the Gasper Formation. The greatest local relief on the unconformity is 5 feet along a distance of 150 feet. If the anomalous thickness of Hartselle in the well in the SE cor. sec. 3, T. 7 S., R. 2 W., is due to filling of a channel eroded into the Gasper Formation, local relief here may be greater than 60 feet. The contact with the Bangor Limestone is gradational. The stratigraphic relationship of the Hartselle and Bangor is discussed in the section on the Bangor.

GROUND WATER.—Wells tapping the Hartselle Sandstone ordinarily yield less than 10 gpm. The sandstones are so fine grained, poorly sorted, and well cemented that most of them are only slightly permeable, and water in the formation is stored and transmitted chiefly in the open spaces along joints. Less commonly, the water is in spaces along bedding planes. If thrust faulting has occurred in the formation, moderate quantities of water may occur locally along the spaces between beds separated by bedding-plane faults.

Thrust faulting has not been observed, but local conditions suggest the presence of faulting. Some of the most productive wells in the Hartselle yield water from the very thin bedded sandstones, siltstones, and shales near the bottom of the formation. The largest yields from these beds have been from wells about 0.8 mile east of Plainview School. A bailing test of one of these wells indicates a yield greater than 20 gpm, which is the largest capacity known for a well tapping the Hartselle.

The basal conglomeratic limestone, which commonly is a good aquifer, is discussed with the Gasper Formation because there is a closer hydrologic relation than there is between the basal conglomeratic limestone and the typical Hartselle.

The Hartselle Sandstone generally cannot supply the quantity of water needed for domestic use; however, the maximum thickness of the formation in the county is only about 120 feet, and water can be obtained from the underlying Gasper Formation in many parts of the area. Water may be obtained also from formations older than the Gasper in a few areas--mostly near the escarpment capped by the Hartselle Sandstone.

BANGOR LIMESTONE

DESCRIPTION.—The Bangor Limestone crops out over a larger area in Morgan County than any other formation--about 160 square miles (pl. 1). Most of the area is in the Moulton Valley physiographic district (fig. 4), a feature that resulted from solution of limestone between two resistant sandstone formations (section A--A' on pl. 1). In much of the eastern part of the county, the Bangor crops out in the escarpment along the Cumberland Plateau. The portion of the formation that crops out in the escarpment diminishes westward until almost all the outcrop area is in the Moulton Valley.

The average thickness of the Bangor is about 340 feet. No place was found in the county where the formation could be accurately measured; chiefly because exposures of the bottom contact are rare. Welch (1958) reports that the Bangor is about 345 feet thick on Monte Sano in Madison County, and 470 to 500 feet in Franklin County. If the change in thickness is at a constant rate, the Bangor is probably about 400 feet thick in the southwest corner of Morgan County and about 350 feet thick in the northeast corner.

The Bangor Limestone generally comprises beds of gray to bluish-gray finely crystalline or very fine grained to coarse-grained thin to very thick bedded partly oolitic limestone and a few beds of olive-gray calcareous shale. Some of the limestone in the upper half of the formation is dolomitic and argillaceous and is interbedded with shale. Chert nodules are common in some of the limestone. The lithology and stratigraphy of the Bangor differ vertically and horizontally.

The Bangor is gradational with the Hartselle Sandstone, and may interfinger with the Hartselle. Beds of Bangor Limestone contain abundant quartz sand grains as much as 50 feet above the basal contact. The base of the Bangor was drawn at the horizon where the lowermost specimens of *Prismopora serrulata* and other index fossils of the Glen Dean Limestone occur. Where the gradational zone is thin, the lowermost part of the Bangor may be limestone or shale that contains little sand, but where the gradational zone is thick, the lowermost part may contain more than 50 percent sand. In wells and outcrops studied south and west of Hartselle, a basal unit in the Bangor comprises very thin to laminated beds of dark-bluish-gray very sandy, silty argillaceous fossiliferous limestone, or a similar calcareous sandstone, interbedded with laminated or very thin bedded shale.

Welch (1958), in his section 22, shows about 10 feet of argillaceous dolomite at the top of the Bangor Limestone. In this report this dolomite is interpreted as the basal bed of the Pennington Formation, because a very thin red or green shale bed, characteristically Pennington, occurs below the dolomite locally.

GROUND WATER.— The water-bearing properties of the Bangor Limestone are as diverse as its lithologic characteristics or its physiographic settings. The argillaceous limestone or dolomitic limestone beds contain few cavities and, therefore, little ground water, but the thick-bedded coarse-grained oolitic limestone beds may contain large cavities and large quantities of ground water. Along the escarpment, water ordinarily drains from the formation and wells yield little water, but in parts of the Moulton Valley, wells yield large quantities of water.

The physiographic setting of the Bangor exerts greater control over its water-bearing properties than any other factor. About 75 percent of its outcrop area is in a basin, the Moulton Valley. The shale in the basal unit of the Bangor and the well-cemented thick-bedded sandstone near the top of the Hartselle Sandstone form a nearly impermeable barrier to the downward movement of ground water. Thus ground water is confined largely to movement within the Bangor. The area is drained chiefly by only two streams, Flint and Cotaco Creeks, which have cut shallow breaches through the barrier formed by the Hartselle Sandstone. The water table is generally shallow. Cavity systems are not extensive and generally are at a depth of less than 50 feet. Water that is obtained at greater depths is probably from small openings along joints rather than solution cavities.

Several hundred wells and springs yield supplies of water from the Bangor Limestone adequate for domestic and stock use; other wells, perhaps an equal number, do not yield supplies adequate for domestic use. Many of the wells of low yields are within a few feet of more productive wells. The difference in yield is a result of local conditions rather than general water-bearing properties of the formation. The municipal well at Falkville (Dodson and Harris, 1961, table 2, well X-11) taps the Bangor and is pumped about 12 hours per day to supply about 30,000 gallons. The well reportedly could yield more than 150,000 gpd. Test well 12-T is 2,000 feet S. 60° W. of the Falkville municipal well, but the yield of the test well was only 33 gpm on June 8, 1961.

The quantity of water obtained from the Bangor is erratic from well to well. However, the Bangor Limestone can be classed as a moderately good aquifer in Morgan County. This is substantiated by the occurrence of many springs that issue from thick-bedded limestone in the Bangor (Dodson and Harris, 1961, table 2). On August 8, 1958, the estimated flow of Hughes Spring was 500 gpm, and on April 13, 1960, the measured flow from the spring was 4,100 gpm (pl. 3). Springs flowing from the Bangor generally are not as large as Hughes Spring, but the minimum flow of several springs probably would be greater than 100 gpm during a drought.

Along the top of the escarpment in the area of outcrop of the Pottsville Formation near Williams Cove Spring (I-266), Lamons Spring (R-125), or Hughes Spring (R-157), wells drilled into the Bangor Limestone might penetrate closely spaced well-developed joints, which could yield enough water for domestic use.

PENNINGTON FORMATION

DESCRIPTION.—The Pennington Formation crops out in a narrow band along the escarpment of the Cumberland Plateau and in outliers in the Moulton Valley district (fig. 4; pl. 1). The thickness of the Pennington ranges from 70 to 150 feet and averages about 100 feet. An unconformity at the top of the Pennington causes local variation in the thickness.

The lowermost bed of the Pennington is a very thin red or green shale that locally separates the Bangor Limestone from the 10-foot thick bed of dolomite included by Welch (1958) in the Bangor. The dolomite is light gray, very fine grained or finely crystalline, argillaceous, and partly calcareous. About 5 to 20 feet of red and green shale that is characteristic of the Pennington overlies the dolomite and is gradational with the overlying limestone. The limestone is medium to light gray, fine grained or finely crystalline, argillaceous, thin to thick bedded, and interbedded with red and green shale. In the middle of this argillaceous limestone, and gradational with it, is an oolitic limestone that is medium to light gray, medium to coarse grained, and thick bedded. The upper 5 to 20 feet of the Pennington consists of the characteristic red and green shale.

GROUND WATER.– The Pennington Formation generally is a poor aquifer; wells rarely yield a supply adequate for domestic use. Several factors account for the poor yield of wells. The Pennington generally crops out in a steep escarpment so that recharge conditions are poor. The impermeable shales at the top and near the base of the formation prevent water in the Pottsville or Bangor from moving to the thick limestone beds in the middle of the Pennington. Cavities in the limestone and dolomite are small and uncommon; however, locally springs issue from caves in the Pennington. Fluctuation of flow from springs issuing from the Pennington generally is great. The flow in the spring branch below the springs at Cole Spring was 360 gpm on April 12, 1960, but it is probably less than 100 gpm during a drought. Conditions reported by drillers indicate that some wells yield water from cavities in the Pennington immediately below the Pottsville-Pennington contact. A chemical analysis of water from one well (table 4, R-115) suggests that the yield is from limestone in the Pennington rather than from sandstone in the Pottsville. A bailing test of this well indicates that its estimated yield of 20 gpm is greater than would be expected from either the Pottsville or the Pennington. A few wells considered to develop water from the Pottsville actually may be supplied from aquifers in the Pennington.

POTTSVILLE FORMATION

DESCRIPTION.–The Pottsville Formation, the only formation of Pennsylvanian age in Morgan County, underlies an area of about 110 square miles in the eastern, southeastern, and southwestern parts of the county (pl. 1). This area is mountainous and is a part of the Cumberland Plateau section of the Appalachian Plateaus physiographic province (fig. 4; Fenneman, 1938, p. 333-342, 691, pl. 3). The maximum thickness of the Pottsville in Alabama is 9,000 feet (Butts, 1926, p. 217), but erosion has removed much of the formation in Morgan County so that its maximum thickness is less than 300 feet.

The Pottsville Formation in the county is composed of fine- to coarse-grained poorly sorted thick to very thick bedded sandstone; very fine grained laminated to thin-bedded silty sandstone interbedded with shale and siltstone; silty to sandy carbonaceous shale; conglomerate; and, locally, a few thin beds or lenses of coal. The sandstones and conglomerates are generally quartzose and are well cemented by calcite. Beds and lenses of conglomerate, which contain a few subangular pebbles of shale from the Pennington Formation, occur locally at the base of the Pottsville. Rocks in the Pottsville are chiefly gray, commonly greenish, olive, or bluish gray, and they generally weather yellowish brown.

A major unconformity separates the Pottsville Formation from the Pennington Formation. Relief of the unconformity in Morgan County may be about 80 feet, as the range in thickness of the Pennington is probably due to this relief. Local relief on the unconformity can be observed along the west side of Alabama Highway 157 southeast of Massey near the county line.

GROUND WATER.—The permeability of the Pottsville is low because the sediments composing the rocks are poorly sorted and the rocks are well cemented. Ground water occurs mainly in openings along fractures and bedding planes. Joints are the most common fractures, and faults occur locally. Few wells yield more than 10 gpm; many supplies are inadequate for domestic needs during a drought. Because of the complex lithology of the Pottsville, yields differ greatly from place to place.

The inadequacy of ground-water supplies from the Pottsville is a critical problem in some parts of the county, for instance in the Union Hill-Morgan City area. The problem will become widespread in areas underlain by the Pottsville as the demand for ground water increases. In scattered areas water can be obtained from wells drilled through the Pottsville into the top of the Pennington Formation. As pointed out in the section on the Bangor Limestone, wells drilled through the Pottsville and Pennington might yield enough water from the Bangor to relieve the critical water shortage in the Union Hill-Morgan City area. Little water is likely to be available from formations below the top of the Pennington in the area underlain by the Pottsville in the south half of the county. Community growth there will depend to a great extent on how well the ground water available from the Pottsville is developed and managed.

POST-PENNSYLVANIAN UNDIFFERENTIATED

DESCRIPTION.—Unconsolidated deposits cover about 95 percent of the bedrock in Morgan County. These deposits are of post-Pennsylvanian age and consist of soil, alluvium, colluvium, residuum, and other unconsolidated materials composed of clay, silt, sand, gravel, and chert rubble. The average thickness of the unconsolidated deposits is estimated to be 30 feet. Generally the thickness ranges from 15 feet for deposits overlying the Pottsville Formation and Hartselle Sandstone to 40 feet for deposits overlying the Tuscumbia Limestone. Locally the unconsolidated deposits overlying the Tuscumbia may be more than 100 feet thick.

GROUND WATER.— Supplies of ground water adequate for domestic use are available from the unconsolidated deposits in many areas of Morgan County. Bailing tests indicate that a few wells yield more than 20 gpm. Supplies from residual deposits overlying sandstone and supplies from alluvial deposits generally are inadequate. Large supplies are developed locally from chert rubble; well K-30 (Dodson and Harris, 1961, table 2) yielded more than 20 gpm between depths of 38 and 48 feet.

Drilled wells develop supplies adequate for domestic use from unconsolidated deposits only in an area less than 3 miles wide along Wheeler Reservoir from Flint Creek to a mile east of Talucah. In other areas only dug wells have proved successful.

Colluvial deposits of broken Hartselle Sandstone are generally not permeable because of their poorly sorted character; however, they are more permeable than the Hartselle and they contain large quantities of water which are slowly released from storage. Much of the water that flows from springs in the Gasper along the escarpment has come from storage in the colluvial deposits of broken Hartselle. The discharge of many of these springs is remarkably constant. In most of the limestone springs in the county the ratio between the high and the low discharge is commonly more than 10 to 1, but it may be as low as 2 to 1 in the springs flowing from the Gasper.

GROUND-WATER RESOURCES

According to Curtis (1953), an average of 11.4 inches of the annual precipitation in the Tennessee Valley region seeps into the ground and becomes ground water. If Morgan County is typical of the areas in the Tennessee Valley region, the daily supply of ground water from rainfall would be about 300 million gallons. This quantity can be considered the theoretical maximum that is available without withdrawal from storage; however, because of hydrologic and economic limits, the quantity that can be obtained will be much less.

Much of the ground water is lost directly to streams, both from the aquifers and from less permeable rock. Seepage from a less permeable formation to streams over a great distance can equal a large volume of water. Among variable factors that will determine the quantity that can be economically produced in the future are locations and depths of new wells, construction and operation costs, pumping rates, and ground-water demand. The investigation of the ground-water resources of Morgan County has shown that many times as much ground water is available in the county as was being used during the period 1957-61.

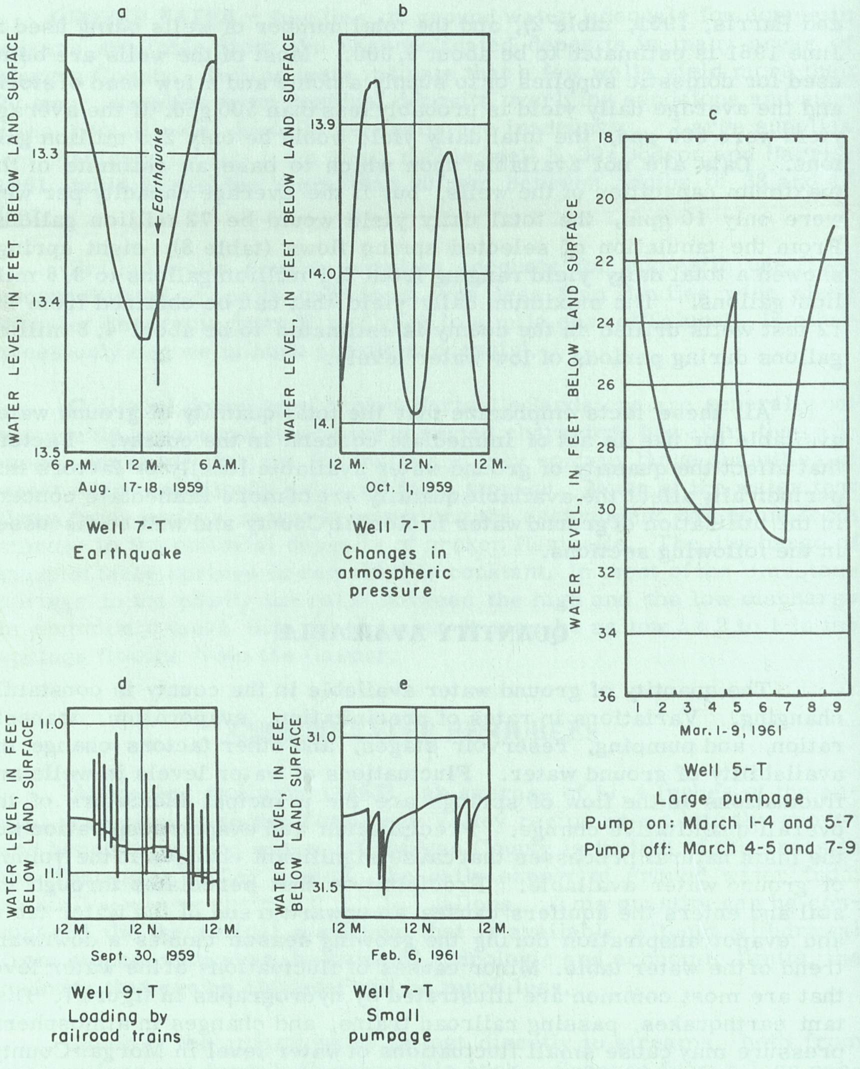
More than 2,500 wells were inventoried in Morgan County (Dodson and Harris, 1961, table 2), and the total number of wells being used in June 1961 is estimated to be about 5,000. Most of the wells are being used for domestic supplies or to supply a home and a few head of stock, and the average daily yield is probably less than 500 gpd. If the average yield were 500 gpd, the total daily yield would be only 2.5 million gallons. Data are not available upon which to base an estimate of the maximum capacities of the wells, but if the average capacity per well were only 10 gpm, the total daily yield would be 72 million gallons. From the tabulation of selected spring flows (table 3), eight springs showed a total daily yield ranging from 2.1 million gallons to 3.6 million gallons. The maximum daily yield that can be obtained from the 12 test wells drilled in the county is estimated to be about 4.3 million gallons during periods of low water levels.

All these facts emphasize that the total quantity of ground water available for use is not of immediate concern in the county. Factors that affect the quantity of ground water available locally or factors that periodically affect the available quantity are of more immediate concern in the utilization of ground water in Morgan County and will be discussed in the following sections.

QUANTITY AVAILABLE

The quantity of ground water available in the county is constantly changing. Variations in rates of precipitation, evaporation, transpiration, and pumping, reservoir stages, and other factors change the availability of ground water. Fluctuations of water levels in wells and fluctuations in the flow of springs are the principal indicators of the overall quantitative change. Precipitation and evapotranspiration are the main natural processes that cause significant changes in the volume of ground water available. Precipitation that percolates through the soil and enters the aquifers causes an upward trend of the water table, and evapotranspiration during the growing season causes a downward trend of the water table. Minor causes of fluctuations of the water level that are most common are illustrated by hydrographs in figure 7. Distant earthquakes, passing railroad trains, and changes in atmospheric pressure may cause small fluctuations of water level in Morgan County, but do not change the quantity of ground water available.

Pumping other wells may cause fluctuations of the water levels in wells tapping the same aquifer. The amplitude of fluctuations may be small or large, depending on the rate of withdrawal, distance from the pumped well, and other factors. The effect of pumping 10 gpm from a domestic well on the water level in well 7-T, 800 feet east, is shown in figure 7e. The effect of pumping 200 gpm from well B-330 at Trinity on the water level in well 5-T, 4,000 feet southeast, is shown in figure 7c. The quantity of available ground water was reduced locally, but the total quantity available in the county was not significantly affected;



Aug. 17-18, 1959

Well 7-T
Earthquake

Oct. 1, 1959

Well 7-T
Changes in atmospheric pressure

Mar. 1-9, 1961

Well 5-T
Large pumpage
Pump on: March 1-4 and 5-7
Pump off: March 4-5 and 7-9

Sept. 30, 1959

Well 9-T
Loading by railroad trains

Feb. 6, 1961

Well 7-T
Small pumpage

Figure 7.—Some causes of fluctuation of water levels in wells in Morgan County.

however, a large number of wells being pumped could reduce the quantity of available ground water in Morgan County. In a few areas near Morgan City and Union Hill, pumpage exceeded the recharge of ground water in 1961, but the problem is not expected to be general throughout the county in the foreseeable future.

The hydrograph of test well 5-T (fig. 8) illustrates the response of water levels to precipitation. The amplitude of water-level fluctuations caused by changes in precipitation are generally greater in well 5-T than in most of the wells in the county; otherwise, the water-level reactions are typical. During or after periods of rainfall the water level rises in the well proportionately to the amount of rainfall, and during periods of little or no rainfall it declines.

Abnormally heavy rains between August 21 and October 10, 1960, caused a sharp rise of water levels in wells in the county. During the 24-hour period ending at 7:00 a. m. August 22, 1960, the precipitation recorded at the Decatur station was 3.99 inches, which is the greatest amount recorded during the period of this investigation. Similar water-level fluctuations were recorded for the other observation wells in the county.

Large seasonal fluctuations of water levels in wells are caused by evapotranspiration, the process by which ground water is lost to the atmosphere, both directly and indirectly. Ground water may evaporate directly to the atmosphere from the soil, if the water table is at or near the land surface, or from springs and seeps (Meinzer, 1923a, p. 82; 1923b, p. 48-50; 1942, p. 414-415). Large quantities of ground water are discharged indirectly by transpiration, the process by which water vapor escapes from plants and enters the atmosphere. Roots of much of the vegetation in the county extend into the capillary fringe or into the zone of saturation below the water table (Meinzer, 1923b, p. 23) and extract ground water during the growing season.

A general decline of water levels begins in Morgan County about the last week of March and continues to about the first week in November, unless modified by abnormally heavy rainfall. Figure 8 shows the decline beginning March 16, 1960, and continuing to August 22, 1960, when the abnormal rainfall reversed the trend. The amplitude of change in water level in well 5-T would ordinarily be about 20 feet.

The surface of a stream draining an area is the base level of the water table in that area, and fluctuations in streamflow will cause fluctuations in the water table. The effect is ordinarily not large in Morgan County, but fluctuations of the impounded level of Wheeler Reservoir may cause greater fluctuations in the volume of ground water available in parts of the county than either evapotranspiration or rainfall. During 1961, extraordinary conditions offered an opportunity to study the

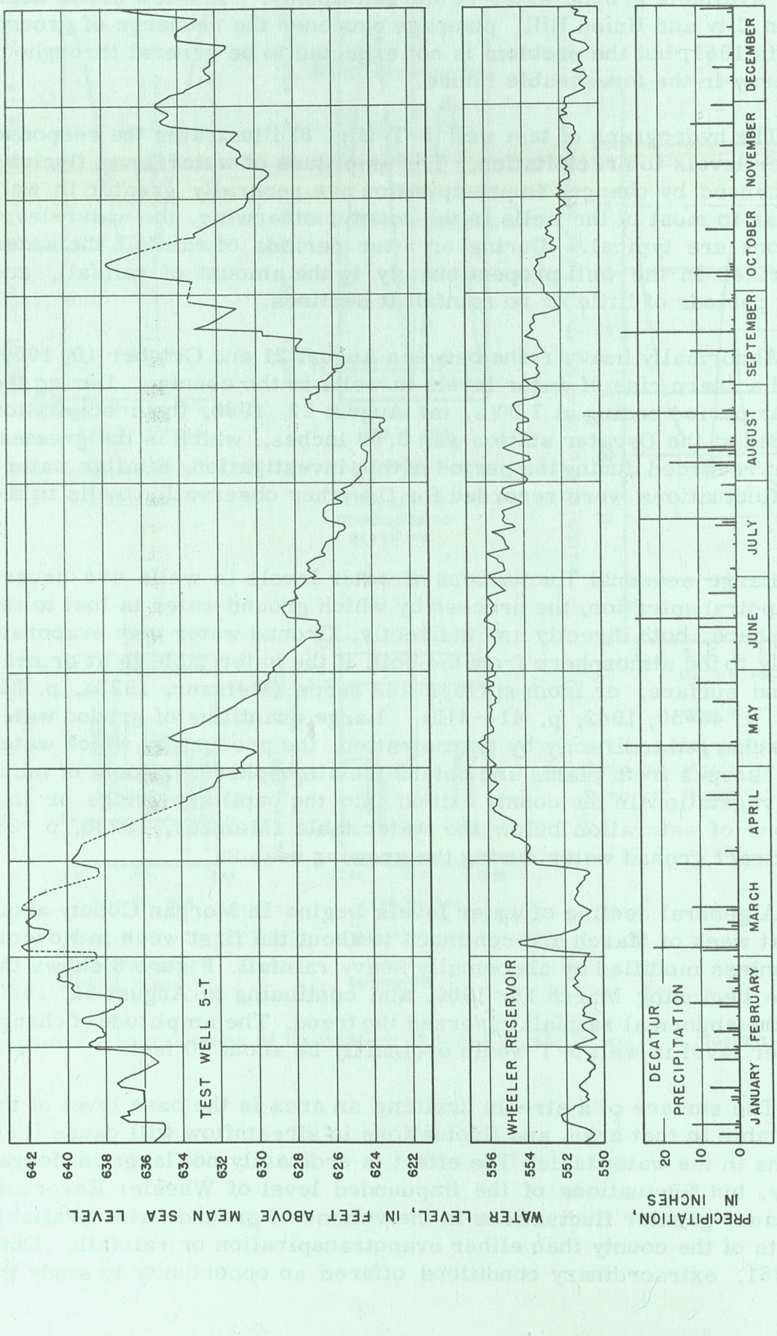


Figure 8.—Hydrographs of test well 5-T and Wheeler Reservoir and graph of the precipitation at Decatur, Ala., during 1960.

effects of reservoir fluctuations on ground-water levels in Morgan County. Floods, beginning February 17, 1961, filled the reservoir to the second highest stage since construction of Wheeler Dam, and the water level in the reservoir fluctuated in response to flood-control operations until March 17, when it began the gradual rise to the annual full-pool stage. Both rainfall and reservoir stages caused fluctuations in ground-water levels, but the fluctuations were much larger than they would have been from the amount of rainfall alone. In the evening of June 2, 1961, the north wall of Wheeler Lock burst while the upstream lock gate was open, and the water level in Wheeler Reservoir dropped 6.5 feet by June 4. The effect on the water level in well 8-T is shown in figure 9. The water level in the reservoir had been held near full-pool stage, about 556 feet above sea level, since April 12. About April 16 the water level in the well began the seasonal decline, but it dropped 3.3 feet after the reservoir level dropped. The level in the well rose with the rise in the reservoir after the gate was closed until June 8, when the water table resumed the seasonal decline.

The change in the quantity of water available during periods of high and low water levels is reflected in part by the change in spring discharges during these periods (table 3).

The quantity of water that is available in a given volume of limestone or sandstone is difficult to determine, because the water-bearing openings of the rocks differ in size and interconnection from place to place. Compact, unfractured limestone yields little or no ground water to wells. Within the zone of fluctuation of the water table in Morgan County, about 10 percent of the total volume of the rock formations may be filled with ground water. If this is true, each foot of fluctuation of the water table, over the whole area of Morgan County, represents a change of about 12.5 billion gallons of ground water. This volume is equal to about 20 million gallons per square mile, or about 30,000 gallons per acre; but these figures cannot be applied to a given area of the size indicated even though the 12.5 billion gallon figure may be valid for the county as a whole. The volume of available ground water is far greater than 30,000 gallons per acre in some areas and is much less in other areas. It is generally greater in the Tennessee Valley district and less in the Little Moulton district and the Cumberland Plateau section (fig. 4).

The fluctuations observed in selected wells and springs are shown on plate 3. The bars represent the difference between the highest and lowest water levels of record and the difference between the maximum and minimum flows from springs. The difference in fluctuation from area to area and from well to well is clearly demonstrated. The fluctuations of flow of springs are representative of limestone springs in the county. The average fluctuation of all wells shown is 14 feet, which would represent a difference within the county of about 175 billion gallons of ground water if 10 percent of the total volume of rock contained

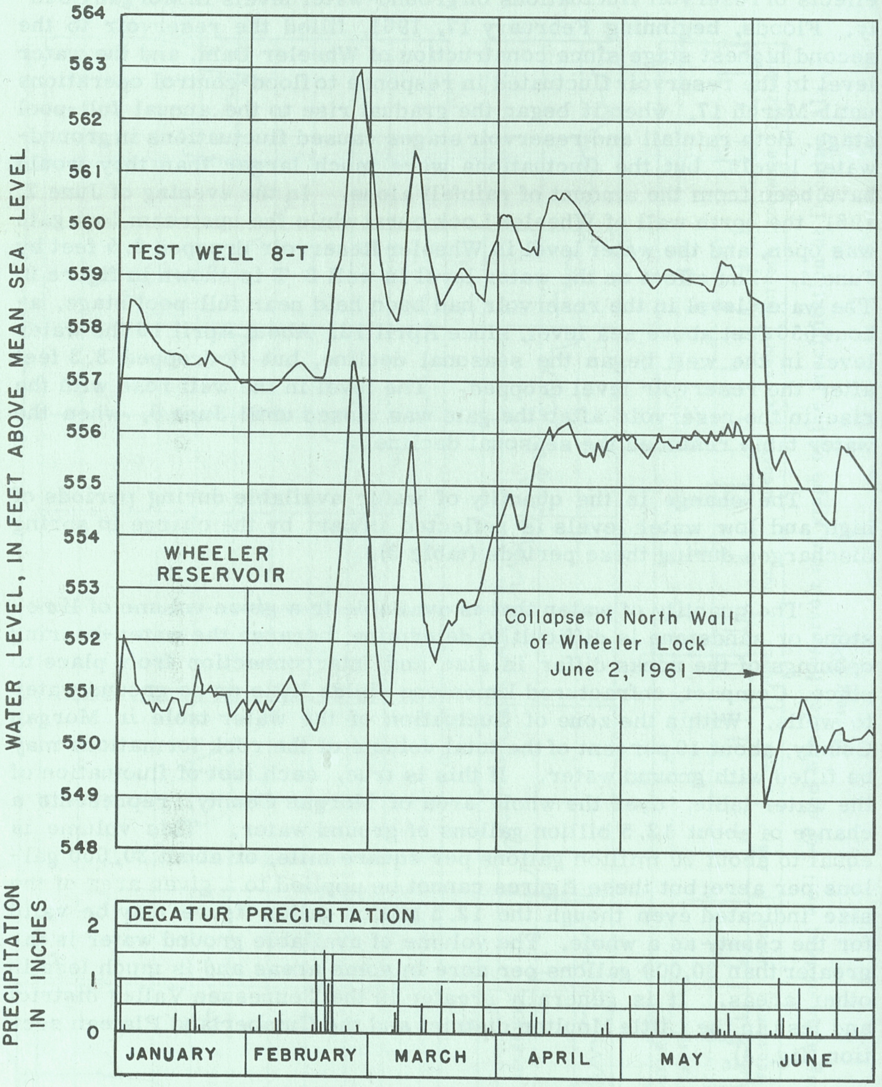


Figure 9.—Hydrographs of test well 8-T and Wheeler Reservoir and graph of the precipitation at Decatur, Ala., from January 1 to July 1, 1961.

Table 3.—*Discharge from springs in Morgan County, Ala.*

Spring no.	Spring name	Water-bearing formation	Estimated flow (gpm)	Date	Measured flow (gpm)	Date of measurement
I-108	Laceys	Gasper Formation	40	8-21-29[1]	450	4-13-60
I-266	Williams Cove	Bangor Limestone	300	5-21-58	660	4-13-60
K-1	Cave	Tuscumbia Limestone	100	10-24-58	3, 800	4-14-60
Q-70	Peck	Bangor Limestone	300	3-10-59	480	4-13-60
R-157	Hughes	Bangor Limestone	500	8- 8-58	4, 100	4-13-60
V-17	Copper	Pottsville Formation	100	3-18-59	150	4-13-60
W-32	Cole	Pennington Formation	50	9-15-58	360	4-12-60
X-93	Blowing	Bangor Limestone	100	4- 8-59	100	4-12-60

[1] Johnston (1933)

ground water.

The capacities of about 25 wells have been determined by pumping tests in Morgan County. The yield of test well 8-T is the highest known in the county, and its maximum yield during the period of water-level high is estimated to be 1,100 gpm. Wells that will yield more than 100 gpm are common in the area within the Tennessee Valley district (fig. 4). The yields of Hughes Spring (Dodson and Harris, 1961, table 2, R-157) and three other springs (table 3), flowing from the Bangor Limestone, indicate the possibility of developing wells that would yield 100 gpm in parts of the Moulton Valley physiographic district.

Several flowing wells have been drilled in the county (Dodson and Harris, 1961, table 2). Little is known about the flows except from test well 12-T, which is less than 1 gpm from the Bangor Limestone. This well has been pumped at 33 gpm (table 2).

STRUCTURAL CONTROL

All the water-bearing formations in Morgan County, except parts of the Pottsville Formation, were deposited in horizontal beds on the bottom of the sea. Later the rocks were tilted, folded, and faulted, and now the beds are only locally horizontal. The structural-geology map shows the present configuration of the top of the Chattanooga Shale (pl. 2).

The regional dip is south about 30 feet per mile. Ground water tends to move through the aquifers in the direction of regional dip, but many factors alter this general trend. The most significant of these factors are local folding, regional and local fractures, faults, and collapse structures.

The rocks do not dip uniformly with the regional dip but are folded into broad anticlines and synclines. The dip of these folds in some places is greater than or opposite to the regional dip. These broad folds control the movement of the water. They also contain local flexures that exert control over the movement of ground water in like manner. Water flows by gravity from anticlines to synclines. Test wells 6-T and 10-T, in structural highs, were dry holes. Test wells 1-T through 5-T and 7-T through 9-T all produced over 50 gpm in structurally low areas. The structural high in the vicinity of Hartselle is the largest in the county. The combined yield of several municipal test wells drilled at Hartselle was less than 100 gpm, and the maximum yield of any one well was probably less than 20 gpm.

Joints, nearly vertical, are the most common fractures in the county and all cavity systems in the limestone aquifers have formed along or have been influenced by joint systems. Figure 5 illustrates the control of joints over the movement of ground water. Other forms of cavities associated with joints have been observed in the county, but most of them are modifications of those shown in figure 5. Although not shown as such, the cavity formed in the zone of fluctuation of the water table, between points C and D, also would ordinarily be formed along a joint. Even where a cavity is formed along another feature, the larger parts of the cavity generally tend to form along joints. Locally, the Pottsville Formation is intensely jointed, and many of the more productive wells in this formation are probably in areas where jointing is closely spaced and well developed.

A thrust fault with associated high-angle faults, strike-slip faults, and small folds is exposed in the Pottsville and Pennington Formations in Morgan County, an occurrence similar to that in Tennessee (Stearns, 1955). Good exposures of faults in the county are few, and faulting in the Pottsville and Pennington has been observed only south of Florette (figs. 10, 11, 12). In sec. 26, T. 7 S., R. 2 W., the exposed Pottsville-Pennington thrust fault has at least two possible strike-slip faults and numerous small folds associated with the thrust fault. Part of the exposed fault plane appears to be a high-angle normal fault (fig. 10), but the fault here is a strike-slip fault, for movement was chiefly horizontal, perpendicular to the road cut. The fault plane probably is nearly horizontal at a shallow depth below the road cut, as the angle of the

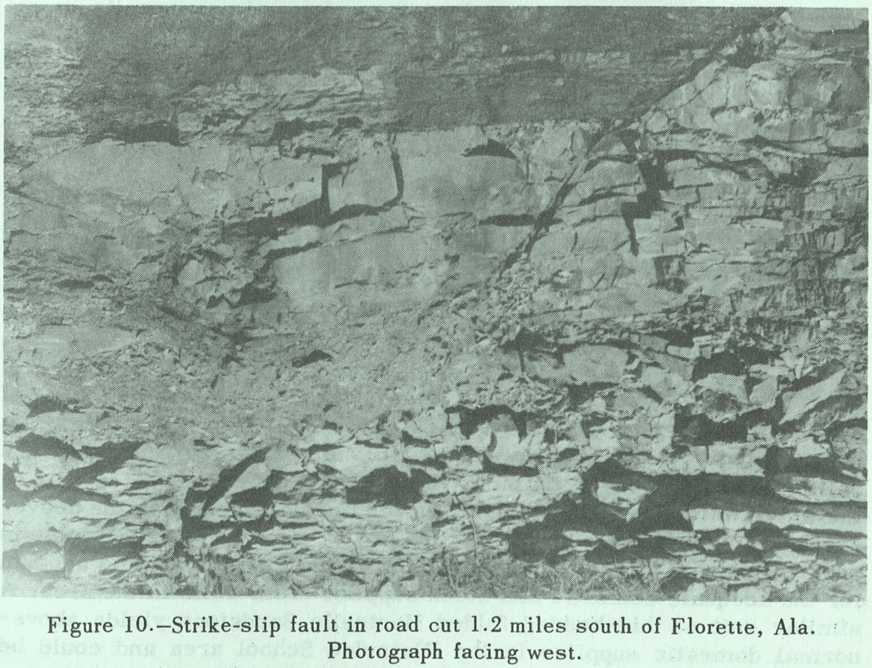


Figure 10.–Strike-slip fault in road cut 1.2 miles south of Florette, Ala. Photograph facing west.

fault is much less at the base than it is elsewhere in the cut. Figure 11 shows the crushed and broken sandstone in a zone more than 25 feet thick above the fault plane. In association with the thrust fault, small compression folds occur in the laminated to very thin bedded sandstone of the Pottsville Formation. These folds were observed in the northern part of Cullman County southwest of Lacon and are due possibly to the thrust fault mapped in sec. 22, T. 8 S., R. 4 W.

A well drilled in the SW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 22, T. 8 S., R. 4 W., west of Lacon, penetrated the Pottsville-Pennington contact about 160 feet below the altitude of that contact in an outcrop about 300 feet north of the well. The block of sandstone in the Pottsville Formation in sec. 10, T. 8 S., R. 2 W., is a thrust-fault slice with the Pottsville-Pennington contact approximately 100 feet lower than the surrounding area. The block of sandstone dips to the southeast about 80 feet in 1 mile, or from two to three times the normal rate of regional dip. An increase in dip indicates a monocline from the Cole Springs area east to sec. 10, T. 8 S., R. 2 W., and then northeast to sec. 18, T. 7 S., R. 1 E. Structure along this line possibly is related to the exposed thrust fault in sec. 26, T. 7 S., R. 2 W. A thrust fault similar to that shown in figure 11 is exposed in the Trinity quarry about a mile north of Trinity, and evidence of bedding-plane faulting has been found in other quarries in the county.

Springs flowing from the Pottsville Formation generally do not exceed 10 gpm; but locally three springs by their unusually high flow indicate movement of water along a possible thrust fault near the base of the Pottsville Formation. Peck Mountain Spring (Q-68) flowed at an estimated rate of 100 gpm on March 12, 1959. The spring flows from the coarse sandstone and conglomerate in the thrust fault area exposed in a road cut along Morgan County Highway 35, 2 miles south of Florette, Ala. Copper Spring (V-17) flowed at a measured rate of 150 gpm on April 13, 1960. No surface evidence of thrust faulting was observed in the vicinity of Copper Spring, or at Lynn Spring (S-39), which flowed at an estimated rate of 50 gpm on August 1, 1958; but their high yields are attributed to thrust faulting in the base of the Pottsville Formation or the Pennington Formation.

In some wells the aquifer is a unit composed of thin interbeds of shale, siltstone, and very fine grained sandstone--a lithology that might be expected to yield little or no water. Slippage along the beds, resulting from faulting in the thrust-fault zone, opened up spaces where the water was stored and transmitted and could account for the above-average yields of wells Q-69, R-122, R-197, and V-72. Small folds in association with the thrust fault south of Florette (fig. 12) could account for the adequate domestic and stock supplies from wells in the area. A similar unit of thin-bedded folded Hartselle Sandstone yields above-normal domestic supplies in the Plainview School area and could be related to a fault here similar to the area south of Florette.

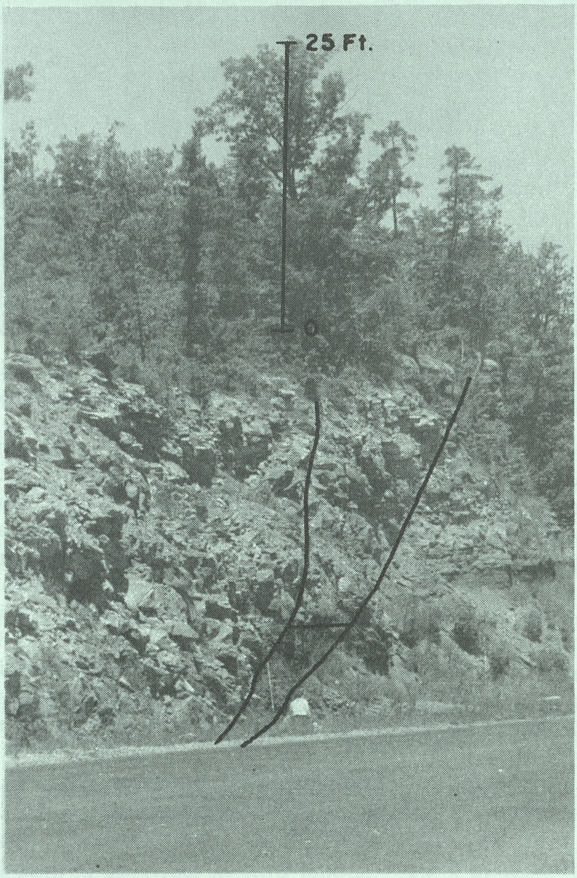


Figure 11.—Thrust fault in road cut 1.2 miles south of Florette, Ala., showing crushed and broken zone above fault plane. Photograph facing west.

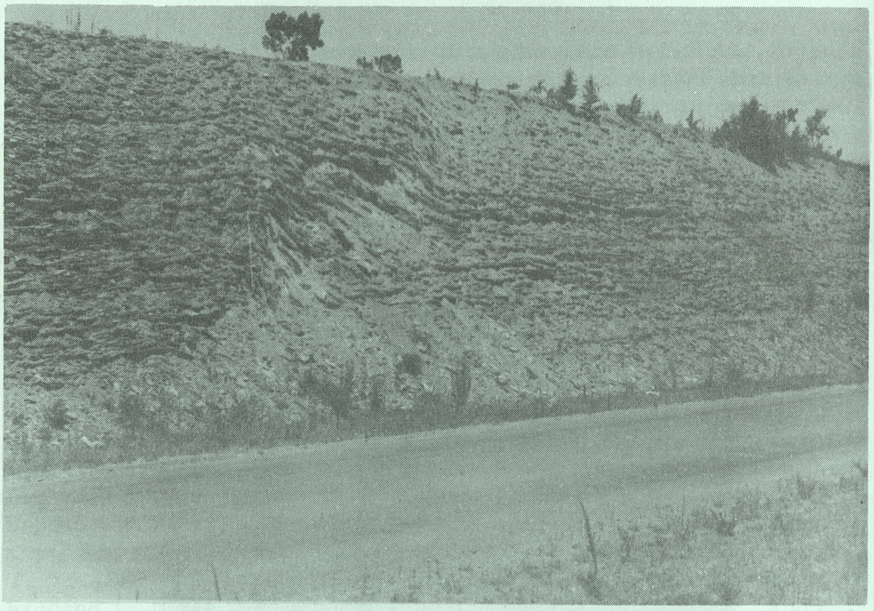


Figure 12.—Small fold associated with thrust fault about 1.5 miles south of Florette, Ala.; cut is 30 feet deep. Photograph facing west.

The Hartselle Sandstone has collapsed into solution cavities in the underlying limestone of the Gasper Formation in parts of Morgan County. Colluvial deposits of broken Hartselle Sandstone are abundant along the outcrop area of the Hartselle (pl. 1) near the escarpment bordering the Little Mountain district (fig. 4). Blocks of sandstone in these collapse structures may be more than 100 feet wide and 20 feet thick. Collapse structures are present in an area about half a mile wide and extending about a mile along Flint Creek in secs. 26 and 35, T. 5 S., R. 4 W. Broken sandstone from the Hartselle is exposed in road cuts and outcrops, and shale that is probably from the Gasper is exposed in a road cut in the SE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 26; the sandstone and the shale are at least 200 feet below their normal position. Test well 8-T in this area passed through 105 feet of unconsolidated deposits. Mr. C. H. Elliott, a driller, reported that in the SE$\frac{1}{4}$NE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 35, a well drilled to a depth of 180 feet did not reach bedrock. In the Talucah area, and over an area of more than 6 square miles southward, the Gasper Formation locally has been completely removed by solution, and the Hartselle has collapsed onto the Ste. Genevieve Limestone.

The broken rock in collapse structures is more important as an area of recharge to the bedrock aquifers than as an aquifer itself. Wells in the collapsed Hartselle Sandstone generally yield supplies inadequate for domestic use except in an area half a mile wide in secs. 26 and 35, T. 5 S., R. 4 W. The high yield of test well 8-T is related more to recharge in an area of collapse than to its location on a structural low.

DEPTH AND AREAL LIMITS OF AQUIFERS

The depth of an aquifer below the land surface is generally a limiting factor in the development of ground water. Joints become tighter and more widely spaced because of fundamental physical properties of the crust of the earth, and the circulation of ground water decreases because of the change in the characteristics of the joints. The solvent action of the ground water decreases mainly because of the gradual reduction in the carbon dioxide content in the ground water. As the water moves downward from the water table through the carbonate rocks, chemical reaction removes the carbon dioxide, and the products of reaction are added to the ground water. At some indeterminate depth, the solvent action of the ground water in forming solution cavities theoretically ceases. All other factors being equal, the yield of ground water from a given formation in Morgan County decreases with an increase in depth below the land surface. The decrease in circulation and the decrease in the solvent action of ground water with depth are the principal reasons for the decrease in yield of the aquifers downdip from the area of outcrop.

On a regional scale, the water-bearing rocks of Morgan County probably react as five aquifers (fig. 13). These regional aquifers are separated by confining beds so that they are mainly recharged from precipitation in their areas of outcrop, and the yield of the aquifers decreases with an increase in distance to their outcrop in much the same way as the yield decreases with depth. The yield of an aquifer is probably reduced to a near minimum in Morgan County within 2 miles downdip from the outcrop of the top contact of the aquifer; however, the change is gradual and inconsistent so that no boundaries can be drawn.

TENNESSEE VALLEY DISTRICT

The water resources in the Tennessee Valley physiographic district (fig. 4) are obtained from the lowermost regional aquifer in Morgan County (fig. 13), and most of the available ground water is in cavities and fractures in the Tuscumbia Limestone and the Fort Payne Chert. The water resources of the individual geologic formations and the properties of the aquifers, such as the water-level fluctuations, are discussed in foregoing sections of this report. On a regional scale, however, the hydrology of the Tennessee Valley district reacts as a unit. The shale in the middle part of the Gasper Formation and the Hartselle Sandstone are the confining beds that separate the aquifer in the Tennessee Valley district from aquifers in the rest of the county.

Pumping tests, both by the U.S. Geological Survey and by private organizations, generally have been confined to the Tennessee Valley district. The results of the tests run on 10 wells drilled in the Tennessee Valley district are given in table 2. Pumping rates ranged from

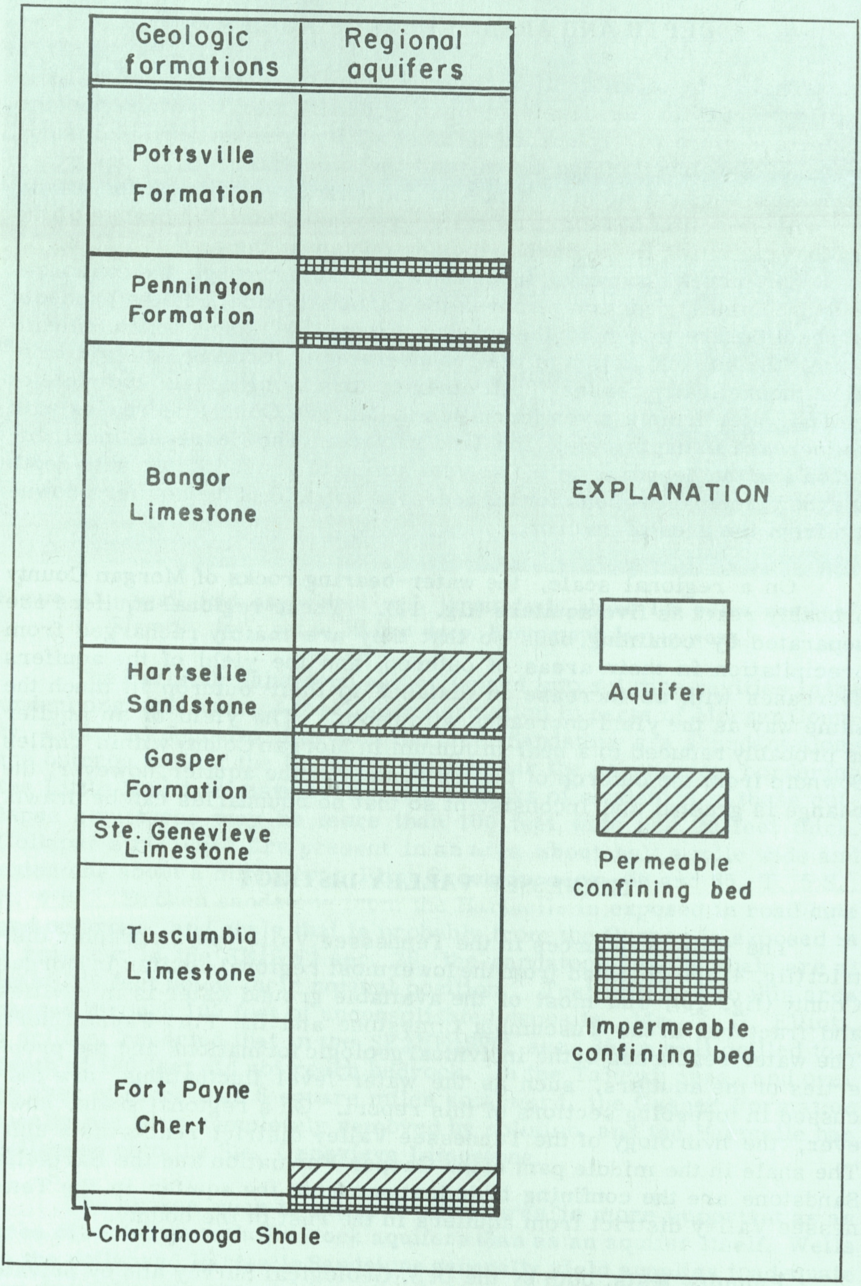

Geologic formations
Regional aquifers
Pottsville Formation
Pennington Formation
Bangor Limestone
Hartselle Sandstone
Gasper Formation
Ste. Genevieve Limestone
Tuscumbia Limestone
Fort Payne Chert
Chattanooga Shale
EXPLANATION
Aquifer
Permeable confining bed
Impermeable confining bed

Figure 13.–Regional aquifers in the geologic formations.

55 to 350 gpm. Figures 14 and 15 show the drawdown and recovery of water levels during pumping tests run on wells 1-T and 8-T; locations of the wells are shown in figure 3. Pumping tests were not made on two of the wells, 6-T and 10-T, because water was developed chiefly at shallow depths in the Tuscumbia Limestone; however, bailing tests indicate that each well would yield about 30 gpm.

All test wells drilled as part of this investigation are finished in limestone. A quantitative evaluation of pumping-test data is difficult, since the geometry of the solution system is not known. However, the specific capacity (gallons per minute per foot of drawdown) determined from a pumping test is a guide to the potential yield from the aquifer at the well site. Specific capacity may be determined by pumping a well at a constant rate and measuring the drawdown of the water level in the well until the water level becomes reasonably constant. If the point of water entry into the well is known, for example the top of a water-producing cavity, the total yield of the well may be calculated by multiplying the specific capacity by the net available drawdown--that is, the distance in feet from the seasonally low water level to the point of water entry in the well. Similarly, specific capacity may be used to calculate the depth of pump setting necessary to allow a planned rate of pumping--the planned rate of pumping is divided by the specific capacity to give the pumping water level in feet below the seasonally low nonpumping water level.

Sanford and West (1960) investigated the use of step-drawdown pumping tests to evaluate the characteristics of a well finished in limestone. The pumping tests of wells 1-T and 8-T were run in three steps (table 2). Experience has shown that sometimes erroneously optimistic specific capacities are determined from wells pumped at low rates. Therefore, it is likely that the specific capacities of 10 and 14 gpm per foot of drawdown calculated for wells 1-T and 8-T are more accurate than the larger specific capacities calculated from lower rates of discharge of the same wells. If the wells were pumped at their maximum capacities, they would probably show lower specific capacities. During the pumping tests, the wells yielded an aggregate of 2.4 mgd (million gallons per day), which is probably as much water as is ever used in a day from all wells in Morgan County. The total yield of the wells during dry seasons probably would be more than 4 mgd.

Yields of the test wells can be considered typical for wells penetrating the Tuscumbia Limestone and Fort Payne Chert in the Tennessee Valley district. The greatest resource of ground water in Morgan County is in the Tennessee Valley district and is available for the increasing industrial demand.

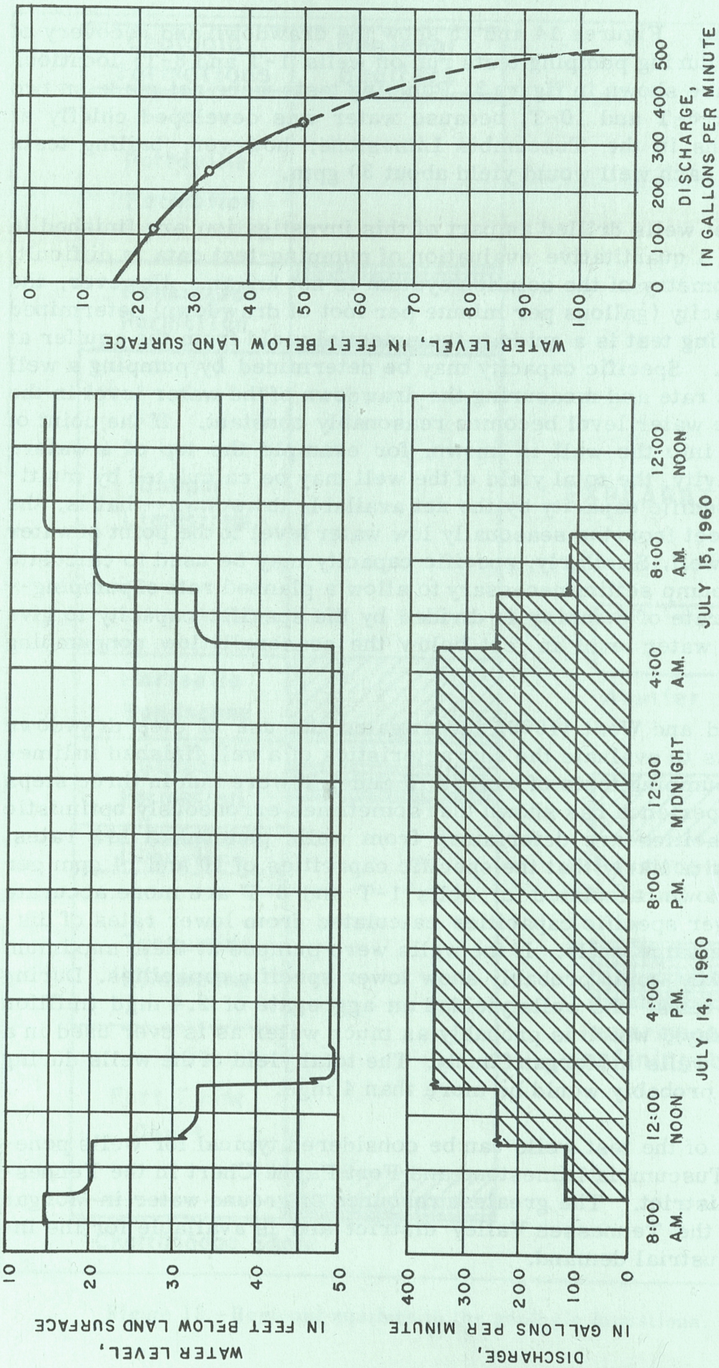


Figure 14.—Fluctuation of the water level in test well 1-T during pumping.

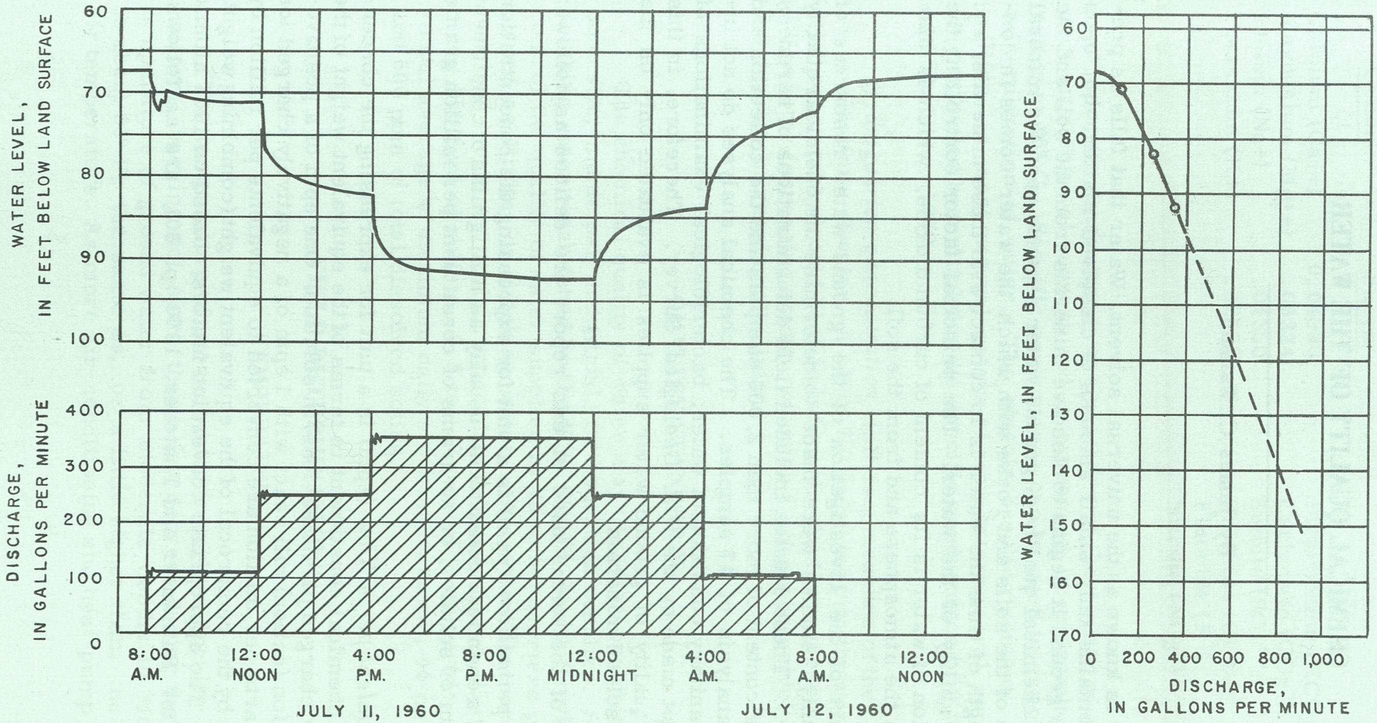


Figure 15.—Fluctuation of the water level in test well 8-T during pumping.

CHEMICAL QUALITY OF THE WATER

By James C. Warman

Water is known as the universal solvent. Water that falls as precipitation contains only small amounts of dissolved matter, but upon reaching the ground it begins to dissolve minerals from the soil and the rocks. The chemical quality of ground water depends upon the mineral composition of the soils and rocks with which the water comes in contact, the length of time the water is in contact with these minerals, and the solvent ability of the water. The principal factor controlling the solvent action of water is its content of carbon dioxide, which is dissolved from the atmosphere and from the soil.

As part of the investigation of the ground-water resources of Morgan County, studies were made to determine the chemical quality of the water. These studies included field determinations of hardness and chloride content of more than 2,000 samples and the collection and laboratory analysis of 47 samples. The chemical analyses do not indicate the sanitary condition of water; bacteriological examinations of water are not made by the U.S. Geological Survey. Therefore, in this report the quality of ground-water supplies is evaluated only on the basis of dissolved minerals.

Some of the terms used in this report are defined as follows:

Part per million (ppm) is a unit for expressing the concentration by weight of a chemical constituent, usually as milligrams of constituent per kilogram of solution, or as grams of constituent per million grams of solution.

Equivalent per million (epm) is a unit for expressing the concentration of a chemical constituent in terms of the equivalent weight of the electrically charged particles (ions) in solution. One epm of a positively charged ion (cation) will react with 1 epm of a negatively charged ion (anion). Parts per million are converted to equivalents per million by multiplying by the reciprocal of the equivalent weight (combining weight) of the ion. The appropriate conversion factors, based on 1954 atomic weights (after Rainwater and Thatcher, 1960, p. 80), are as follows·

Cation	Factor
Calcium (Ca^{++})	0.04990
Magnesium (Mg^{++})	.08224
Sodium (Na^{+})	.04350
Potassium (K^{+})	.02558

Anion	Factor
Bicarbonate (HCO_3^-)	0.01639
Carbonate (CO_3^-)	.03333
Sulfate (SO_4^{--})	.02082
Chloride (Cl^-)	.02820
Fluoride (F^-)	.05263
Nitrate (NO_3^-)	.01613

Specific conductance is a measure of the ability of water to conduct an electrical current and is expressed in micromhos per centimeter at 25° C. Specific conductance can be used to estimate the total mineralization of water. The dissolved-solids content, in parts per million, in most natural waters of moderate mineral content may be approximated by multiplying the specific conductance by 0.65 (Rainwater and Thatcher, 1960, p. 84).

Hydrogen-ion concentration (pH) is a measure of the relative acidity or alkalinity of water. A pH of 7.0 indicates that the water is neutral (hydrogen and hydroxyl ions in balance). A pH progressively less than 7.0 denotes increasing acidity, whereas a pH progressively greater than 7.0 denotes increasing alkalinity.

QUALITY STANDARDS

The chemical quality of water may limit or prohibit its use for domestic, municipal, industrial, or irrigation supplies. Standards for drinking water established by the U.S. Public Health Service (1962) to control the quality of water supplied by common carriers generally are quoted as limits for drinking water. According to these standards, supplies should not contain more than 0.3 ppm of iron, 250 ppm of chloride, 250 ppm of sulfate, 0.8 to 1.7 ppm of fluoride (depending on the annual average of maximum daily air temperatures), 45 ppm of nitrate, and 500 ppm of total dissolved solids.

FIELD DETERMINATIONS

TEMPERATURE

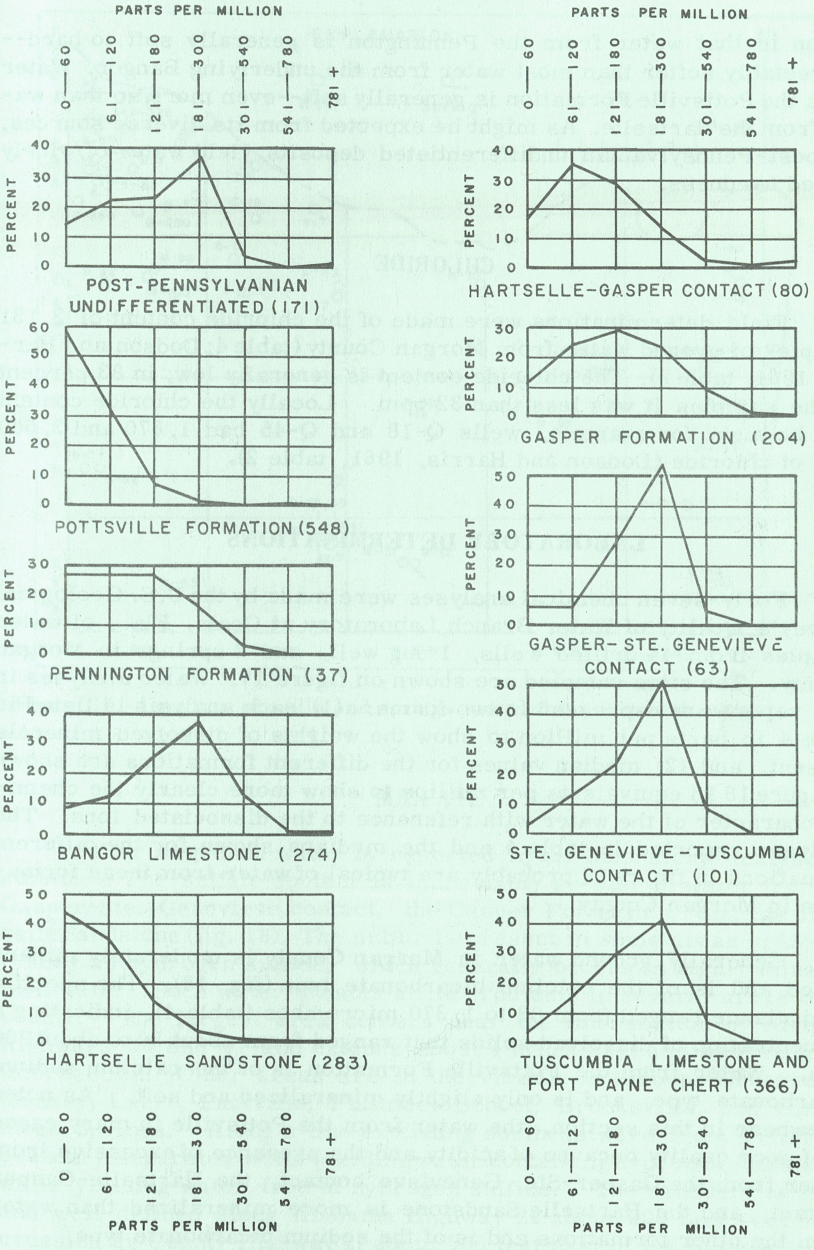
The temperature of ground water in a given locality is generally uniform, varying not more than a few degrees during the year. The temperature of ground water from moderate depths in Morgan County is about 63° F, the same as, or a little higher than, the mean annual air temperature. As more air-conditioning and heat-pump systems are installed the temperature of ground water becomes increasingly important.

HARDNESS

Excessive hardness is the most common objectionable property of water. The greater the concentration of calcium and magnesium salts, the harder the water. Hardness causes scum in bathtubs, gray laundry, scale in hot-water tanks and lines, excessive soap consumption, and other problems; however, hard water is not generally believed to have harmful effects on man. Although specific limits of hardness cannot be set, the following are general criteria:

Hardness	Rating	Utility
0-60	Soft	Suitable for most uses without softening.
61-120	Moderately hard	Suitable for many uses except in some industrial applications.
121-180	Hard	Softening required for use in laundries and some other industries.
More than 180	Very hard	Softening required for most uses.

Hardness determinations were made in the field and laboratory for 2,127 samples of ground water from Morgan County (Dodson and Harris, 1961, table 2; table 4). Results of these determinations are summarized in figure 16. Ground water is generally very hard from the Fort Payne Chert and overlying aquifers up to and including the contact zone between the Ste. Genevieve Limestone and the Gasper Formation. The limestones of the Gasper yield water that is moderately hard to very hard; and a further decrease in hardness is illustrated in figure 16 for the Hartselle Sandstone-Gasper Formation contact zone, where the water generally is moderately hard. This decrease in hardness is attributed to the effect of the shale unit in the Gasper, which is the first persistent confining bed above the Chattanooga Shale. Thus, in the contact zone the soft water from the Hartselle mixes with and beneficiates the harder water from the upper limestone unit of the Gasper. Figure 16 illustrates the abrupt change from the soft water in the Hartselle to the very hard water in the Bangor Limestone. There were fewer hardness determinations made of water from the Pennington Formation; therefore, the graph is less well defined. However, the indi-



Number in parentheses is number of samples analyzed.

Figure 16.—Hardness of ground water in Morgan County.

cation is that water from the Pennington is generally soft to hard--appreciably softer than most water from the underlying Bangor. Water from the Pottsville Formation is generally soft--even more so than water from the Hartselle. As might be expected from its diverse sources, the post-Pennsylvanian undifferentiated deposits yield water of widely varied hardness.

CHLORIDE

Field determinations were made of the chloride content of 2, 131 samples of ground water from Morgan County (table 4; Dodson and Harris, 1961, table 2). The chloride content is generally low; in 83 percent of the samples it was less than 32 ppm. Locally the chloride content may be high; for example, wells Q-18 and Q-45 had 1, 670 and 3, 600 ppm of chloride (Dodson and Harris, 1961, table 2).

LABORATORY DETERMINATIONS

Forty-seven chemical analyses were made by the U. S. Geological Survey's Quality of Water Branch Laboratory at Ocala, Fla., of water samples from 44 drilled wells, 1 dug well, and 2 springs in Morgan County. The sites sampled are shown on figure 17. Water analyses in this report are expressed in two forms: (1) each analysis is listed in table 4 in parts per million to show the weights of dissolved minerals present, and (2) median values for the different formations are shown in figure 18 in equivalents per million to show more clearly the chemical character of the water with reference to the dissociated ions. The analyses reported in table 4 and the medians shown for the different formations in figure 18 probably are typical of water from these formations in Morgan County.

Generally ground water in Morgan County is moderately mineralized and is of the calcium bicarbonate type (fig. 18). The specific conductance ranged from 83 to 1, 370 micromhos (table 4), indicating a concentration of dissolved solids that ranged from about 50 to about 900 ppm. Water from the Pottsville Formation is of the calcium sodium bicarbonate type, and is only slightly mineralized and soft. As noted elsewhere in this section, the water from the Pottsville in many cases is of poor quality because of acidity and the presence of excessive iron. Water from the Gasper-Ste. Genevieve contact, the Hartselle-Gasper contact, and the Hartselle Sandstone is more mineralized than water from the other formations and is of the sodium bicarbonate type.

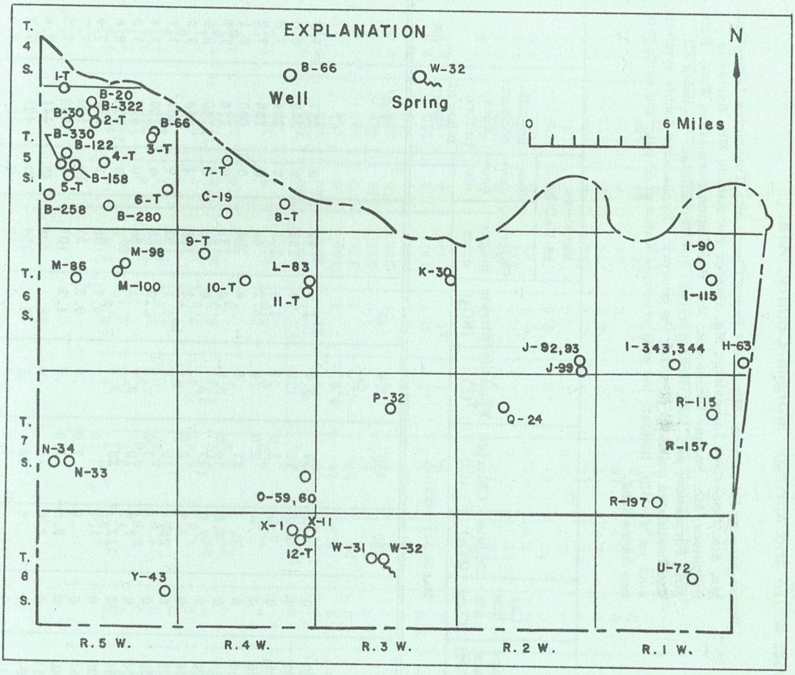

EXPLANATION
B-66
Well
W-32
Spring
0
6 Miles
N
T. 4 S.
T. 5 S.
T. 6 S.
T. 7 S.
T. 8 S.
I-T
B-20
B-322
B-30
2-T
B-66
B-330
3-T
B-122
4-T
7-T
5-T
B-158
B-258
6-T
C-19
B-280
8-T
9-T
M-98
M-86
M-100
10-T
L-83
11-T
K-30
I-90
I-115
J-92,93
J-99
I-343,344
H-63
P-32
Q-24
R-115
N-34
N-33
R-157
O-59,60
R-197
X-1
X-11
12-T
W-31
W-32
Y-43
U-72
R. 5 W.
R. 4 W.
R. 3 W.
R. 2 W.
R. 1 W.

Figure 17.—Location of wells and springs sampled for chemical analysis.

SULFATE

Sulfur in ground water is reported in the laboratory analyses as sulfate. The sulfate content is appreciably greater in water from the Gasper-Ste. Genevieve contact, the Gasper Formation, and the Hartselle Sandstone (fig. 18). The sulfur is present in some areas of Morgan County as hydrogen sulfide, which generally occurs in highly mineralized water. Such water creates acute problems in several areas of the county. The largest area centers near the intersection of Alabama Highways 36 and 67 and extends about 4 miles east and west from the intersection. Other areas are in the vicinity of Stroups Crossroads, Massey, Lacon, Falkville, Plainview School, Brooksville, and Valhermosa Springs. Along a line extending southeastward from Trinity, a boundary separates wells yielding water containing hydrogen sulfide and wells yielding water free of hydrogen sulfide. The boundary is sharp and well defined along Alabama Highway 24 about 900 feet west of the crossing by County Highway 1, about 500 feet east of the intersection of County Highways 1 and 61, along the paved county road in the $SW\frac{1}{4}SE\frac{1}{4}NE\frac{1}{4}$ sec. 10, T. 6 S., R. 5 W., and along the road west of Basham. In an area extending 1 to 4 miles southwest of this line, water from wells

Table 4.—*Chemical analyses of water from wells and springs, Morgan County, Ala.*

Well or spring: Numbers with "T" suffix denote U.S. Geological Survey test wells; other numbers correspond to those used by Dodson and Harris (1961, table 2).

Water-bearing formation: Mfp, Fort Payne Chert; Mt, Tuscumbia Limestone; Ms, Ste. Genevieve Limestone; Mg, Gasper Formation; Mh, Hartselle Sandstone; Mb, Bangor Limestone; Mp, Pennington Formation; IPpv, Pottsville Formation; pIP, post-Pennsylvanian undifferentiated--includes all unconsolidated material covering the bedrock. Hyphenated double symbols, such as Mt-Mfp, indicate the well produces water at or near the contact of two formations.

Well or spring	Date of collection	Water-bearing formation	Temperature (° F)	Iron (Fe)1/	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Hardness as $CaCO_3$		Specific conductance (micromhos at 25° C)	pH
															Calcium, magnesium	Noncarbonate		
				Parts per million														
U.S. Public Health Service drinking water standards				0.3							250	250	0.6 to 1.7	45			770 2/	
1-T	7-15-60	Mfp	62	.00	29	4.7	81	...	220	0	2.8	54	3.0	1.9	92	0	517	7.9
2-T	11-16-60	Mfp	62	.00	45	9.1	19	...	202	0	3.6	10	1.9	.0	150	0	355	8.0
3-T	2-21-58	Mfp	62	.00	27	8.4	9.2	...	135	0	7.0	3.0	.7	1.4	102	0	224	7.5
4-T	2-28-61	Mt	63	.02	33	.4	4.2	0.4	103	0	.8	5.0	.3	1.3	84	0	186	7.2
5-T	12-23-59	Mt-Mfp	62	.00	74	5.7	53	...	286	0	21	67	.8	.8	208	0	680	8.1
6-T	6-13-61	Mt	..	.00	29	22	19	1.4	226	0	6.8	4.0	3.0	.0	163	0	376	7.7
7-T	7-20-59	Mfp	64	.01	4.8	6.3	260	...	430	0	7.6	147	13	.0	38	0	1,140	8.0
8-T	7-12-60	Mfp	62	.00	48	4.4	1.9	...	166	0	2.4	2.0	.2	.3	138	2	259	7.9
9-T	11-24-59	Mt-Mfp	64	.00	62	1.8	17	...	192	0	26	10	.8	1.1	162	4	381	7.7
10-T	6-13-61	Mt	62	.01	29	3.3	1.7	.4	105	0	.3	3.0	.2	.0	86	0	169	7.4
11-T	5- 3-61	Mt-Mfp	62	.01	53	8.8	42	2.0	284	0	7.6	10	2.7	.1	168	0	477	7.5
12-T	1-24-61	Mb	62	.00	1.6	.5	250	...	408	28	112	25	3.3	.0	6	0	1,030	8.8
B-20	5-14-58	Mt	63	.01	38	2.4	1.5	...	126	0	1.0	.0	.1	4.7	105	2	210	7.6
B-30	5-14-58	Mt	62	.00	20	1.7	2.9	...	58	0	.2	7.0	.0	9.3	57	10	134	7.3
B-66	2-21-58	Mt	62	.05	30	8.0	8.1	...	140	0	8.5	3.0	.6	1.3	108	0	233	7.5
B-122	5-12-58	Mt	63	.01	74	4.7	9.7	...	214	0	8.5	18	.0	19	204	28	441	7.6
B-158	4-29-60	Mt	62	.00	51	6.6	24	...	104	0	.8	42	.1	78	154	69	442	7.7
B-258	5-14-58	Mg-Ms	65	.00	1.2	1.0	245	...	444	0	135	5.0	9.6	1.0	7	0	984	8.1

B-280	5-14-58	Mt	63	.00	79	15	4.8	...	302	0	8.5	8.0	.8	2.9	258	11	493	7.9
B-322	9-21-60	Mt	62	.00	49	4.3	1.0	...	164	0	.4	2.0	.0	2.1	140	6	261	7.7
B-330	5-31-61	Mt	62	.01	69	1.0	2.6	.6	207	0	5.6	4.0	.2	.2	176	6	338	7.5
C-19	5-15-58	pIP	65	.01	40	.5	2.2	...	123	0	2.0	3.0	.0	1.9	102	1	211	7.4
H-63	5-14-58	IPpv	62	.00	2.4	1.2	11	...	8	0	.0	10	.0	17	11	4	83	6.5
I-90	4-29-60	Mg-Ms	65	.00	67	2.2	2.2	...	206	0	4.8	4.0	.0	3.0	176	7	343	8.1
I-115	4- 6-59	Mg	62	.00	85	17	11	...	334	0	86	8.0	1.3	6.5	282	8	701	7.8
I-343, 344	4-29-60	IPpv	65	3.6 3/	5.6	3.4	7.0	...	13	0	26	3.5	.1	.0	28	18	104	6.8
J-92, 93	4- 6-59	Mg	61	.00	42	1.2	2.3	...	126	0	4.4	4.0	.0	3.9	110	6	227	7.4
J-99	4- 9-59	Mh	62	.00	52	18	52	...	212	0	138	6.6	.8	.7	204	30	623	7.8
K-30	4- 6-59	pIP	63	.00	96	2.6	7.3	...	256	0	3.2	22	.1	21	250	40	522	7.7
L-83	4- 6-59	Mt	61	.01	40	21	25	...	276	0	5.6	16	3.0	.4	186	0	454	7.8
M-86	5-14-58	Mg-Ms	64	.01	42	7.5	103	...	310	0	58	37	.8	.2	136	0	691	7.4
M-98	4- 9-59	Ms-Mt	62	.00	84	1.6	2.2	...	241	0	13	3.5	.1	.0	216	18	401	7.8
M-100	4- 9-59	Ms-Mt	..	.00	69	23	12	...	326	0	22	6.0	1.5	.4	266	0	538	8.0
N-33	5-15-58	Mb	64	.02	6.4	4.6	348	...	842	0	2.0	50	3.8	.1	35	0	1,370	8.3
N-34	4- 6-59	Mb	63	.00	52	2.8	3.1	...	162	0	3.4	5.0	.1	5.1	141	8	280	7.7
O-59, 60	4- 6-59	Mh-Mg	61	.00	12	1.0	8.0	...	51	0	7.2	8.5	.1	11	34	0	146	6.8
P-32	4-29-60	Mh-Mg	64	.00	.8	.7	224	...	508	12	19	7.0	4.0	.0	5	0	856	8.5
Q-24	5-12-58	Mh-Mg	66	.00	9.6	4.4	118	...	324	0	13	10	2.2	.1	42	0	552	8.1
R-115	4-29-60	IPpv	63	1.40 3/	41	2.3	2.9	...	130	0	11	.0	.1	.1	112	6	229	7.9
R-157	4- 6-59	Mb	..	.00	25	1.1	1.9	...	81	0	3.8	3.0	.1	1.5	67	0	144	7.6
R-197	4-29-60	Mp	64	.00	26	5.6	12	...	77	0	45	14	.1	3.8	88	25	280	7.3
U-72	5- 2-60	IPpv	64	.33 3/	16	5.1	10	...	92	0	5.2	3.0	.1	.0	61	0	164	7.5
W-31	2- 6-61	Mp	62	.00	60	25	50	...	392	0	21	12	1.3	.1	252	0	650	8.2
W-32	4- 6-59	Mp	60	.00	33	.4	1.5	...	98	0	2.8	2.3	.0	2.8	84	4	173	7.6
X-1	5-14-58	Mh	63	.01	2.8	2.2	140	...	354	0	1.2	16	1.2	.0	16	0	576	7.9
X-11	5-15-58	Mb	65	.01	93	6.8	18	...	264	0	44	18	.1	24	260	44	580	7.9
Y-43	4-29-60	Mb	64	.00	59	1.7	1.8	...	190	0	.4	1.0	.1	1.1	154	0	302	8.1

1/ In solution at time of analysis unless otherwise noted.
2/ Calculated.
3/ Total iron.

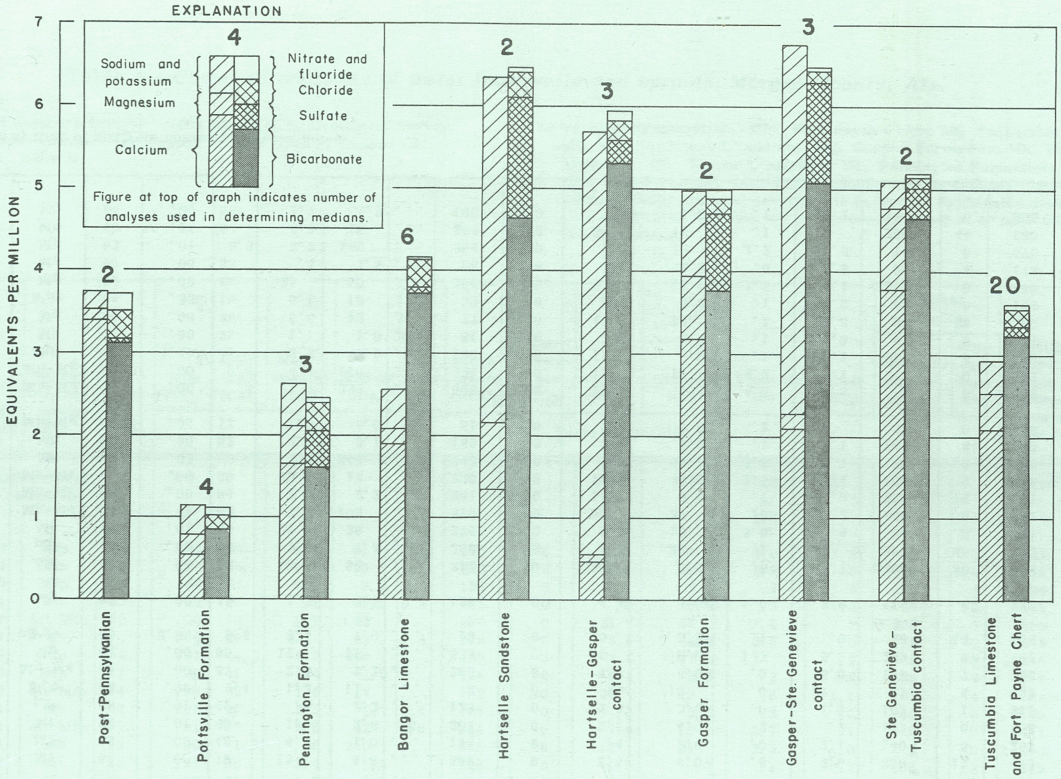


Figure 18.—Median values, by aquifers, of dissolved constituents in ground water in Morgan County.

drilled below the valley floor generally contains hydrogen sulfide. The boundary is less distinct southeast of Basham.

CARBON DIOXIDE

Water from well N-33 contains an extraordinary quantity of carbon dioxide(?), and upon release of pressure the gas is given off and a white mineral precipitates. The water does not contain hydrogen sulfide; neither do other wells in the vicinity.

FLUORIDE

Most fluoride minerals are only slightly soluble and are present in most natural waters in small amounts. The literature contains many references to the beneficial effect of optimum amounts of fluoride in drinking water as an aid in the reduction of tooth decay in children and to the detrimental effect of excessive amounts of fluoride in the mottling of children's teeth. The U. S. Public Health Service (1962) states that the optimum concentrations of fluoride are between 0.7 and 1.2 ppm, depending upon the annual average of maximum daily air temperatures; presence of fluoride in average concentrations greater than two times the optimum values constitutes grounds for rejection of the supply.

Figure 19 shows the location of 57 wells and springs from which water samples were collected for fluoride analysis and the fluoride content of the water in parts per million. Several wells produced water having excessive amounts of fluoride. There is no correlation recognized between the concentration of fluoride and the geologic environment in Morgan County.

NITRATE

Nitrate concentrations in unpolluted water seldom exceed 10 ppm. Nitrate and chloride are major components of animal wastes and fertilizers, and the occurrence of abnormally high concentrations of both constituents suggests possible pollution of the water. Nitrates in large amounts interfere with the dyeing of some textiles. Hem (1959, p. 239) cites studies by four different workers who link nitrate in domestic water supplies to cyanosis in infants. Waters should be considered hazardous for infants if concentrations given in the usual "sanitary" analysis exceed 10 ppm nitrate *expressed in terms of nitrogen (N)*. Analyses made by the Geological Survey report nitrate in parts per million of NO_3^-, and as NO_3^- the concentration should not exceed 45 ppm as recommended by the U. S. Public Health Service (1962). Except in water from well B-158, nitrate concentrations listed in table 4 are less than 25 ppm.

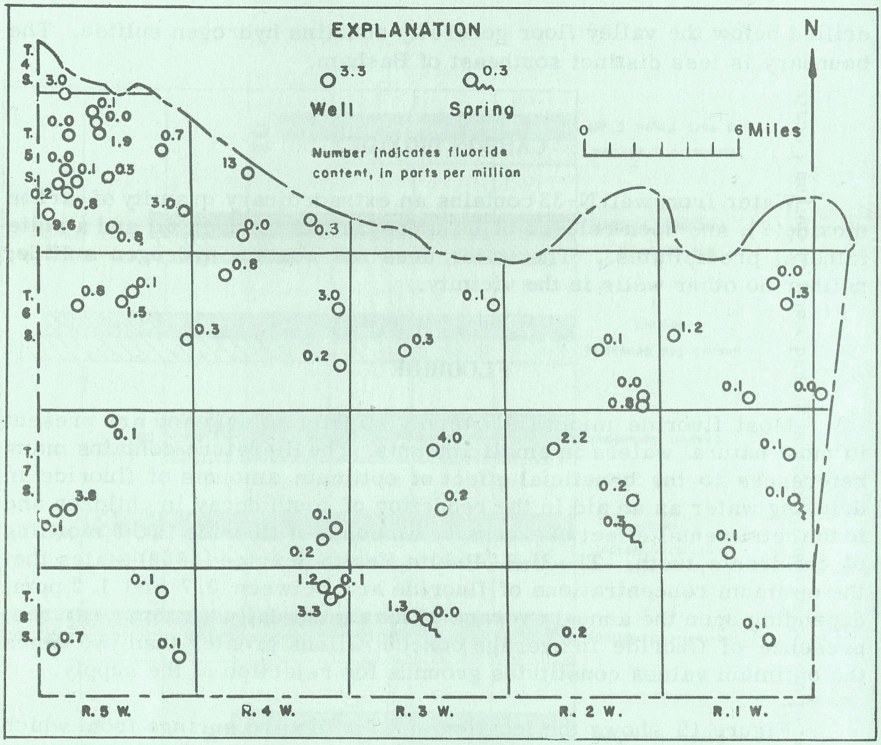

EXPLANATION
3.3
Well
0.3
Spring
Number indicates fluoride content, in parts per million
0
6 Miles
N
T. 4 S.
T. 5 S.
T. 6 S.
T. 7 S.
T. 8 S.
R. 5 W.
R. 4 W.
R. 3 W.
R. 2 W.
R. 1 W.
3.0
0.1
0.0
0.0
1.9
0.7
0.0
0.1
0.3
13
0.2
0.8
3.0
9.6
0.8
0.0
0.3
0.8
0.8
0.1
1.5
3.0
0.1
0.0
1.3
0.3
0.2
0.3
0.1
1.2
0.0
0.8
0.1
0.0
0.1
4.0
2.2
0.1
3.8
0.1
0.2
0.2
0.1
0.1
0.2
0.3
0.1
0.1
1.2
0.1
3.3
1.3
0.0
0.7
0.1
0.2
0.1

Figure 19.—Fluoride in ground water in Morgan County.

Anything in solution in nonionized form is not normally reported in terms of epm; therefore, for silica, iron, and certain other constituents, concentrations are generally expressed in parts per million or other weight-based units.

SILICA

The silica content of water from six wells tapping the Tuscumbia Limestone and (or) the Fort Payne Chert ranged from 2. 3 to 11 ppm, well within generally accepted limits for most uses.

IRON

One of the most annoying quality-of-water problems is the presence of excessive iron. Water from many wells contains dissolved iron, which causes "red water." Manganese has a similar effect; however, it is much less abundant in nature than iron and is generally present in lower concentrations. Some wells contain iron bacteria, which are living organisms that feed and multiply on metal piping and pump surfaces. These iron bacteria may be easily killed by chlorination and removed by filtration. The U.S. Public Health Service (1962) recommends that in drinking and cooking water on carriers subject to Federal quarantine regulations iron should not exceed 0.3 ppm and manganese should not exceed 0.05 ppm. These limits are not based on toxicity but on esthetic and taste considerations. Iron can produce brown stains on plumbing fixtures and laundry; produce an objectionable flavor and appearance in tea, coffee, and other beverages; and, where the iron is insoluble, form sludge and deposits in pipelines and water heater coils. Industry's tolerance for iron varies, but concentrations exceeding 1 to 2 ppm generally are not satisfactory. For many process waters, iron concentrations exceeding 0.01 or 0.02 ppm result in a product of inferior quality. Iron-bearing waters may be successfully treated with polyphosphate, manganese greensand filters, zeolite filters, or chlorination or aeration followed by filtration. Selection of the correct method of treatment depends upon the type and amount of iron present in the water.

Water from the limestone aquifers in Morgan County generally contains little iron; but water from the sandstone aquifers, the Hartselle Sandstone and Pottsville Formation, ordinarily contains iron that in many cases is in objectionable amounts. Most iron determinations in table 4 were made of the iron in solution at the time of analysis. Because iron is generally a problem in water from the Pottsville, three of the four samples from that formation were analyzed for total iron. The results are:

H-63	0.00 ppm iron in solution
I-343, 344	3.6 ppm total iron
R-115	1.4 ppm total iron
U-72	.33 ppm total iron

Each of the total iron determinations exceeds the standard of 0.3 ppm established by the U.S. Public Health Service (1962).

pH

The pH of potable water is not pathologically significant; however, the pH of a water indicates its chemical activity toward metal surfaces. The pH of naturally occurring soft water is usually lower than that of hard water. Low pH in well or spring water is ordinarily caused by free carbon dioxide, which forms carbonic acid when dissolved in water. Water that has a low pH is corrosive to iron and galvanized piping, tanks, and plumbing equipment, and, to a lesser extent, copper. The water may become rusty red, blue, or green. As the pH increases, the corrosive activity of the water normally decreases; however, excessively alkaline waters are corrosive to some metals, particularly zinc. The pH value also has a marked effect upon the efficiency of chlorine treatments. A decrease in the pH (and an increase in the temperature) will accelerate both the rate and extent of chlorine reactions (Am. Water Works Assoc., 1950, p. 207). Other chemical treatments of water are also influenced by pH although the effect is less than in chlorination. Water having extreme pH values generally cannot be used by industry.

Acidic waters are commonly treated with either a neutralizing filter (for example, lime or soda ash) or a polyphosphate solution feeder. The neutralizing filter contributes additional hardness to the water; for this and other reasons, a solution feeder is generally more satisfactory.

Of the 47 samples analyzed from Morgan County, the pH ranged from 6.5 to 8.8 (table 4). Water from the Pottsville Formation in many cases is acidic.

SUMMARY

The chief aquifers in Morgan County are the Tuscumbia Limestone and Fort Payne Chert of Mississippian age. Ground water in these formations occurs mainly in solution cavities and fractures. The maximum yield from wells penetrating solution cavities in the Tuscumbia Limestone and Fort Payne Chert, determined from the results of test pumping, is about 1,100 gpm. Supplies of ground water in the county were adequate for all needs in 1961, except in a few local areas where domestic supplies were inadequate. Many times as much ground water is available as is being used. The largest supplies of ground water available for future industrial development are in the area within the Tennessee Valley physiographic district. Large supplies of ground water are available for future development also in parts of the Moulton Valley physiographic district.

The chemical quality of the water from wells and springs in Morgan County is satisfactory for most ordinary purposes, although hydrogen sulfide and the excessive iron content are problems in a few small areas.

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BASIC DATA

Table 5.—*Sample logs of test wells in Morgan County, Ala.*

	Thickness (feet)	Depth (feet)
Test Well 1-T		
NE¼NW¼ sec. 5, T. 5 S., R. 5 W.		
Soil, red	45	45
Limestone boulders and chert rubble, yellow	38	83
Fort Payne Chert:		
Upper unit:		
Limestone, light-olive-gray, very fine to very coarse grained, partly oolitic	11	94
Limestone, light-olive-gray, very fine grained, slightly dolomitic	4	98
Dolomite, light-olive-gray, very fine grained, very calcareous, petroliferous	4	102
Chert, light-bluish-gray, weathered	3	105
Limestone, light-olive-gray, very fine grained; contains coarse-grained calcite fossil detritus, dolomitic; very light bluish gray chert, mostly near bottom of unit	9	114
Limestone, yellowish-gray, very fine to very coarse grained; very light to light-bluish-gray chert about 1 foot thick near middle of unit	17	131
Limestone, light-olive-gray, very fine grained; contains coarse-grained calcite fossil detritus, dolomitic; very light bluish gray chert	4	135
Middle unit:		
Chert, bluish-white to bluish-gray; light-olive-gray very fine grained partly silicified petroliferous dolomite; light-olive-gray to yellowish-gray very fine grained limestone; medium-olive-gray shale, mostly at top of unit	38	173

Table 5.—*Sample logs of test wells in Morgan County, Ala.*—Continued

	Thickness (feet)	Depth (feet)
Test Well 1-T--Continued		
Fort Payne Chert--Continued		
Middle unit--Continued		
Dolomite, greenish-gray, very fine grained, mostly silicified; greenish-gray chert, composed of completely silicified dolomite; some dark-greenish-gray shale; some bluish-gray chert	22	195
Lower unit:		
Dolomite, greenish-gray, very fine grained, partly silicified; some dark-greenish-gray shale; a few fragments of bluish-gray chert	39	234
Dolomite, pale-green to light-greenish-gray and greenish-gray, very fine grained; greenish-white calcite crinoid stems and stem plates; dark-greenish-gray shale	30	264
Chert, bluish-gray	3	267
Dolomite, pale-green to light-greenish-gray, very fine grained	3	270
Shale, light-greenish-gray, probably the Maury Formation	1	271
Chattanooga Shale:		
Shale, brownish-gray and dark-brownish-gray, pyritic; light-greenish-gray very fine to medium grained poorly sorted quartzose calcareous sandstone at top and bottom of formation	5	276
Test Well 2-T		
NW$\frac{1}{4}$SE$\frac{1}{4}$ sec. 9, T. 5 S., R. 5 W.		
Soil, red and yellow; chert rubble	48	48

Table 5.–*Sample logs of test wells in Morgan County, Ala.*–Continued

	Thickness (feet)	Depth (feet)
Test Well 2-T--Continued		
Tuscumbia Limestone:		
Limestone, very light olive gray, very fine to very coarse grained, fossil detritus, some oolites.	12	60
Limestone, yellowish-gray, fine- to coarse-grained, fossil detritus, partly oolitic . . .	29	89
Limestone, light-greenish-gray, very fine to coarse-grained, mostly fine-grained; very light bluish gray chert	26	115
Limestone, light-olive-gray, very fine to coarse-grained, mostly fine-grained; medium-bluish-gray chert	23	138
Fort Payne Chert:		
Upper unit:		
Limestone, very light olive gray, very fine grained, dolomitic; very light olive gray very fine grained calcareous dolomite; very light bluish gray to medium-bluish-gray chert, replaces dolomite	8	146
Limestone, light-olive-gray and yellowish-gray to white, very fine to very coarse grained, fossil detritus; some light-olive-gray chert	27	173
Limestone, very light olive gray, very fine grained, dolomitic; bluish-gray and light-olive-gray to yellowish-gray chert, completely silicified limestone	8	181
Middle unit:		
Limestone, yellowish-white to yellowish-gray, very fine grained, contains very coarse grained fossil detritus; yellowish-gray to light-olive-gray chert, completely silicified limestone; some light-bluish-gray chert . .	27	208

Table 5.—*Sample logs of test wells in Morgan County, Ala.*—Continued

	Thickness (feet)	Depth (feet)
Test Well 2-T--Continued		
Fort Payne Chert--Continued		
Middle unit--Continued		
Chert, bluish-white to medium bluish-gray; yellowish-gray to light-olive-gray chert, completely silicified limestone	4	212
Cavity; mud, sand, and rubble about a foot thick at bottom	5	217
Limestone, light-olive-gray, fine-grained . .	3	220
Lower unit:		
Dolomite, yellowish-gray and light-olive-gray to medium-greenish-gray, very fine grained, partly calcareous; bluish-white to medium-bluish-gray chert; very light brownish gray to brownish-gray and yellowish-gray to olive-gray chert; light-greenish-gray very fine grained dolomitic limestone.	24	244
Dolomite, light-greenish-gray to medium-greenish-gray, very fine grained and very finely crystalline, partly calcareous, partly silicified; very light brownish gray to brownish-gray chert, completely silicified dolomite; bluish-white to light-bluish-white chert; some dark-gray shale .	40	284
Dolomite, light-greenish-gray to medium-greenish-gray, very fine grained to finely crystalline, partly calcareous; light-greenish-gray chert, completely silicified dolomite; some dark-gray shale.	21	305
Dolomite, light-greenish-gray to greenish-gray, very fine grained, partly silicified; yellowish-gray calcite crinoid stems and stem plates; light-greenish-gray chert, completely silicified dolomite; some light-olive-gray chert and brownish-gray shale .	14	319

Table 5.—*Sample logs of test wells in Morgan County, Ala.*—Continued

	Thickness (feet)	Depth (feet)
Test Well 2-T--Continued		
Fort Payne Chert--Continued		
Lower unit--Continued		
Dolomite, grayish-green to light-greenish-gray, very fine grained and very finely crystalline, about 50 percent silicified; some white to grayish-green and light-greenish-gray chert, completely silicified dolomite; greenish-gray and brownish-gray partly silicified shale	19	338
Limestone, pinkish-gray to very light brownish gray, medium-grained; contains abundant pinkish-white calcite crinoid stems and bluish-white to light-bluish-gray silicified crinoid stems; light-greenish-gray shale, less than half a foot thick, probably the Maury Formation	5	343
Chattanooga Shale:		
Shale, light-brownish-gray to brownish-black, pyritic; yellowish-white to olive-gray very fine to coarse-grained, mostly fine-grained, poorly sorted calcareous quartzose sandstone at top and bottom of formation. Formation contains conodonts	10	353
Test Well 3-T		
NE¼NE¼ sec. 14, T. 5 S., R. 5 W.		
Soil, red	10	10
Chert rubble, brown and yellow	27	37

Table 5.—*Sample logs of test wells in Morgan County, Ala.*—Continued

	Thickness (feet)	Depth (feet)
Test Well 3-T--Continued		
Fort Payne Chert:		
Upper unit:		
Limestone, very light olive gray, very fine to medium-grained, partly dolomitic; some light-bluish-gray chert.	67	104
Limestone, very light olive gray, very fine to coarse-grained; very light bluish gray chert	17	121
Middle unit:		
Dolomite, greenish-gray, very fine grained, partly silicified; bluish-white to very light bluish gray chert.	16	137
Dolomite, greenish-gray, very fine grained, partly silicified; very light bluish gray to bluish-gray chert	18	155
Lower unit:		
Dolomite, greenish-gray, very fine grained; light-bluish-gray to bluish-gray chert; unit contains abundant very light greenish gray calcite crinoid stem plates	85	240
Dolomite, greenish-gray, very fine grained; very light greenish gray calcite crinoid stem plates; light-greenish-gray shale, less than half a foot thick, probably the Maury Formation.	6	246
Chattanooga Shale:		
Shale, brownish-gray to dark-brownish-gray, pyritic; light-greenish-gray very fine to medium-grained poorly sorted calcareous quartzose sandstone at top and bottom of formation.	4	250

Table 5.—*Sample logs of test wells in Morgan County, Ala.*—Continued

	Thickness (feet)	Depth (feet)
Test Well 4-T		
$NE\frac{1}{4}NE\frac{1}{4}$ sec. 21, T. 5 S., R. 5 W.		
Soil, red	15	15
Chert rubble, yellow	24	39
Tuscumbia Limestone:		
Limestone, very light olive gray, fine- to coarse-grained, partly oolitic; some light-bluish-gray to medium-bluish-gray chert	18	57
Limestone, very light olive gray to light-olive-gray, fine- to coarse-grained, oolitic	29	86
Limestone, very light olive gray to light-olive-gray, very fine grained to finely crystalline, in part very coarse grained; some light-bluish-gray chert	10	96
Limestone, very light olive gray to light-olive-gray, in part medium-olive-gray, very fine to coarse-grained, in part very coarse grained and oolitic	22	118
Fort Payne Chert:		
Upper unit:		
Dolomite, very light olive gray, very fine grained, calcareous; some bluish-gray chert	3	121
Limestone, very light olive gray to light-olive-gray, very fine to coarse-grained, in part oolitic and silicified; bluish-white to bluish-gray chert; very light olive gray to light-olive-gray chert; some very light olive gray calcareous shale	36	157
Limestone, very light olive gray, very fine to very coarse grained; bluish-white to light-bluish-gray chert; very light olive gray chert, completely silicified limestone; some light-olive-gray to olive-gray shale	48	205

Table 5.—*Sample logs of test wells in Morgan County, Ala.*—Continued

	Thickness (feet)	Depth (feet)
Test Well 4-T--Continued		
Fort Payne Chert--Continued		
Upper unit--Continued		
Limestone, light-brownish-gray, very fine to coarse-grained; light-bluish-gray to bluish-gray chert; light-brownish-gray chert, completely silicified limestone	5	210
Limestone, greenish-gray, medium- to coarse-grained; some bluish-gray and greenish-gray chert, completely silicified limestone; some light-greenish-gray and brownish-gray shale.	10	220
Middle unit:		
Dolomite, light-olive-gray to olive-gray, very fine grained, calcareous to very calcareous, partly petroliferous; light-bluish-gray chert; light-olive-gray chert, completely silicified dolomite and limestone; light-olive-gray very fine grained dolomitic limestone; some greenish-gray and olive-gray shale	26	246
Chert, light-olive-gray to medium-olive-gray, completely silicified dolomite; light-olive-gray to olive-gray and greenish-gray very fine grained dolomite; bluish-gray chert; some olive-gray shale.	21	267
Lower unit:		
Dolomite, light-greenish-gray to dark-greenish-gray, very fine grained, partly silicified, argillaceous near bottom of unit; some light-olive-gray and greenish-gray chert; bluish-gray chert; some greenish-gray to dark-greenish-gray and olive-gray shale; light-greenish-gray shale about a foot thick, probably the Maury Formation .	62	329

Table 5.—*Sample logs of test wells in Morgan County, Ala.*—Continued

	Thickness (feet)	Depth (feet)
Test Well 4-T--Continued		
Chattanooga Shale:		
Shale, dark-brownish-gray, pyritic; light-greenish-gray to greenish-gray very fine to coarse-grained poorly sorted quartzose dolomitic and calcareous sandstone at top and bottom of formation	10	339
Test Well 5-T		
SE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 20, T. 5 S., R. 5 W.		
Soil, red and yellow; chert rubble	16	16
Chert rubble and limestone boulders, yellow.	17	33
Tuscumbia Limestone:		
Limestone, yellowish-white, fine- to coarse-grained	5	38
Limestone, yellowish-white to very light olive gray, very fine grained; bluish-white to medium-bluish-gray and yellowish-white to very light olive gray chert, in part silicified limestone.	17	55
Limestone, very light olive gray to light-olive-gray, fine- to coarse-grained, in part oolitic; bluish-white to medium-bluish-gray and yellowish-white to very light olive gray chert, in part silicified limestone.	31	86
Limestone, very light olive gray to olive-gray, coarse-grained, in part fine-grained; bluish-white to medium-bluish-gray and yellowish-white to very light olive gray chert, in part silicified limestone	46	132
Limestone, very light olive gray to olive-gray, very fine to coarse-grained; light-bluish-gray, in part very light olive gray chert	58	190

Table 5.—*Sample logs of test wells in Morgan County, Ala.*—Continued

	Thickness (feet)	Depth (feet)
Test Well 5-T--Continued		
Fort Payne Chert:		
Upper unit:		
Limestone, light-greenish-gray and very light olive gray, very fine to medium-grained, dolomitic, in part silicified; very light bluish gray to medium-bluish-gray chert; light-olive-gray shale	27	217
Limestone, very light olive gray, very fine grained, partly very finely crystalline, dolomitic; bluish-gray chert	7	224
Dolomite, very light olive gray, very fine grained, in part very finely crystalline and silicified; yellowish-gray chert, completely silicified dolomite; bluish-gray chert	9	233
Limestone, yellowish-gray to olive-gray, very fine to very coarse grained, dolomitic; light-olive-gray chert, completely silicified limestone; some bluish-gray chert and olive-gray shale	62	295
Middle unit:		
Limestone, yellowish-gray to olive-gray, fine- to coarse-grained; very light bluish gray to bluish-gray chert; yellowish-gray to light-olive-gray chert; some olive-gray shale........................	14	309
Chert, yellowish-gray to light-olive-gray, completely silicified limestone and dolomite; very light bluish gray to light-bluish-gray chert; yellowish-gray to light-olive-gray very fine grained dolomite; some yellowish-gray to light-olive-gray very fine grained limestone and olive-gray shale	43	352

Table 5.—*Sample logs of test wells in Morgan County, Ala.*—Continued

	Thickness (feet)	Depth (feet)
Test Well 5-T--Continued		
Fort Payne Chert--Continued		
Lower unit:		
Chert, greenish-gray, completely silicified dolomite; medium-greenish-gray to dark-greenish-gray very fine grained silicified dolomite; bluish-gray chert; some brownish-gray shale	25	377
Dolomite, greenish-gray to dark-greenish-gray, very fine grained, partly silicified; some greenish-gray chert, completely silicified dolomite; some bluish-gray chert at top of unit and medium-light-gray and brownish-gray shale; pale-yellowish-gray shale about a foot thick, probably the Maury Formation	44	421
Chattanooga Shale:		
Sandstone, greenish-gray, light-olive-gray, brownish-gray, very fine to coarse-grained, poorly sorted, quartzose, calcareous, in part dolomitic, pyritic, at top and bottom of formation; brownish-gray to brownish-black pyritic shale; greenish-gray to dark-greenish-gray, light-olive-gray to olive-gray sandy silty shale, mostly highly silicified and somewhat fractured, pyrite in the fractures; some medium-light-gray calcareous silty shale	14	435
Test Well 6-T		
NW$\frac{1}{4}$NE$\frac{1}{4}$ sec. 25, T. 5 S., R. 5 W.		
Soil, red and yellow; chert rubble	20	20

Table 5.—*Sample logs of test wells in Morgan County, Ala.*—Continued

	Thickness (feet)	Depth (feet)
Test Well 6-T--Continued		
Tuscumbia Limestone:		
Limestone, light-olive-gray, fine to very coarse grained, in part very fine grained and oolitic	66	86
Fort Payne Chert:		
Upper unit:		
Limestone, greenish-gray, very fine grained, in part silicified	9	95
Limestone, light-greenish-gray to greenish-gray, very fine grained and very finely crystalline, dolomitic, in part silicified; calcite fossil detritus; some bluish-gray chert	9	104
Dolomite, greenish-gray, very fine grained and very finely crystalline, in part calcareous and silicified; some very light bluish gray to light-bluish-gray chert	46	150
Limestone, light-greenish-gray, fine- to coarse-grained and very fine grained, dolomitic, in part silicified, mainly composed of clastic grains of fossil detritus cemented with very fine grained dolomite; bluish-white to light-bluish-gray chert; some medium-greenish-gray shale	40	190
Middle unit:		
Dolomite, greenish-gray, very fine grained, calcareous, 50 percent silicified	15	205
Dolomite, greenish-gray, very fine grained, partly silicified; calcite crinoid stems and stem plates, mostly at top of unit; some dark-greenish-gray shale	36	241

Table 5.—*Sample logs of test wells in Morgan County, Ala.*—Continued

	Thickness (feet)	Depth (feet)
Test Well 6-T--Continued		
Fort Payne Chert--Continued		
Lower unit:		
Dolomite, greenish-gray to medium-greenish-gray, very fine grained and very finely crystalline, 50 percent silicified; some light-bluish-gray to bluish-gray chert at top of unit and greenish-gray shale.	55	296
Chert, bluish-white to light-bluish-gray; light-greenish-gray shale, probably the Maury Formation	3	299
Chattanooga Shale:		
Sandstone, yellowish-gray to very light greenish gray, very fine to coarse-grained, poorly sorted, quartzose, calcareous, pyritic, at top and bottom of formation; greenish-gray and light-olive-gray siltstone; brownish-gray to dark-brownish-gray pyritic shale	6	305
Test Well 7-T		
$NW\frac{1}{4}NW\frac{1}{4}$ sec. 21, T. 5 S., R. 4 W.		
Soil, red.	10	10
Soil, yellow and white; chert rubble.	10	20
Tuscumbia Limestone:		
Limestone, white to medium-light-gray, fine- to medium-grained and finely crystalline, in part oolitic; some light-gray chert	37	57

Table 5.—*Sample logs of test wells in Morgan County, Ala.*—Continued

	Thickness (feet)	Depth (feet)
Test Well 7-T--Continued		
Tuscumbia Limestone--Continued		
Limestone, very light brownish gray to brownish-gray, very light olive gray to light-olive-gray, light-gray to medium-gray, fine- to medium-grained and very finely crystalline.	15	72
Limestone, white to medium-light-gray, very fine to medium-grained and very finely to medium crystalline, in part oolitic	21	93
Fort Payne Chert:		
Upper unit:		
Limestone, greenish-white to greenish-gray, very fine grained to medium-grained and very finely crystalline to medium crystalline; in part bluish-white to medium-bluish-gray pyritic chert	17	110
Limestone, very light gray to medium-dark-gray, fine- to medium-grained and finely to medium crystalline	20	130
Middle unit:		
Limestone, very light gray to medium-light-gray, fine- to medium-grained and finely to medium crystalline; bluish-white to light-bluish-gray chert mostly at top of the unit.	32	162
Lower unit:		
Limestone, white to medium-light-gray and yellowish-gray to very light olive gray, finely to medium crystalline and fine- to medium-grained; bluish-white to dark-bluish-gray, brownish-gray, medium-gray chert.	29	191

Table 5.–*Sample logs of test wells in Morgan County, Ala.*–Continued

	Thickness (feet)	Depth (feet)
Test Well 7-T--Continued		
Fort Payne Chert--Continued		
Lower unit--Continued		
Dolomite, light-gray to medium-gray, very fine to fine-grained; light-gray to medium-gray fine-grained some medium crystalline limestone, containing crinoid stem plates; light-bluish-gray to medium-bluish-gray chert, in part completely silicified dolomite and limestone	49	240
Limestone, very light gray to medium-light-gray and light-greenish-gray to greenish-gray, fine-grained and finely to medium crystalline; light-gray to medium-gray and greenish-gray very fine to fine-grained dolomite; light-gray to medium-gray and dark-greenish-gray shale; light-bluish-gray to medium-bluish-gray chert; white to very light gray calcite	40	280
Limestone, white to light-gray, medium crystalline, probably composed of crinoid stems and stem plates; white to very light bluish gray chert; light-greenish-gray shale, probably the Maury Formation. . . .	6	286
Chattanooga Shale:		
Shale, medium-dark-gray to grayish-black and brownish-gray to brownish-black, pyritic; medium-gray very fine to coarse-grained poorly sorted sandstone.	7	293
Test Well 8-T		
SW$\frac{1}{4}$SE$\frac{1}{4}$ sec. 26, T. 5 S., R. 4 W.		
Soil, red.	35	35
Soil, yellow.	35	70

Table 5.—*Sample logs of test wells in Morgan County, Ala.*—Continued

	Thickness (feet)	Depth (feet)
Test Well 8-T--Continued		
Sandy clay and gravel, yellow	21	91
Fort Payne Chert:		
Upper unit:		
Limestone, light-olive-gray to medium-olive-gray, very fine to very coarse grained, in part dolomitic, highly weathered	58	149
Limestone, yellowish-gray and light-olive-gray to medium-olive-gray, very fine grained and fine- to medium-grained, dolomitic	15	164
Limestone, very light olive gray, very fine grained and medium-grained to coarse-grained, dolomitic; some greenish-gray shale	12	176
Middle unit:		
Limestone, very light olive gray, very fine grained to very coarse grained, dolomitic	8	184
Dolomite, greenish-gray, very fine grained	2	186
Limestone, greenish-gray, very fine to fine-grained, dolomitic; some bluish-gray chert	14	200
Dolomite, very light olive gray, very fine grained, calcareous, about 30 percent silicified; very light olive gray very fine grained limestone, 30 percent silicified; some bluish-gray chert	20	220
Lower unit:		
Dolomite, greenish-gray, very fine grained, 40 percent silicified; some bluish-gray and greenish-gray chert	22	242

Table 5.—*Sample logs of test wells in Morgan County, Ala.*—Continued

	Thickness (feet)	Depth (feet)
Test Well 8-T--Continued		
Fort Payne Chert--Continued		
Lower unit--Continued		
Dolomite, yellowish-gray and greenish-gray, very fine grained, 25 percent silicified; bluish-gray chert; some dark-greenish-gray shale	16	258
Dolomite, greenish-gray, very fine grained, 20 percent silicified; light-bluish-gray chert.	7	265
Dolomite, greenish-gray to medium-greenish-gray, very fine grained, 20 percent silicified; greenish-gray chert, completely silicified dolomite; very light bluish gray to bluish-gray chert	17	282
Dolomite, light-greenish-gray to medium-greenish-gray, very fine grained; calcite crinoid stems and stem plates, mostly at top of unit; bluish-white to light-bluish-gray chert	11	293
Chattanooga Shale:		
Shale, dark-brownish-gray, pyritic; very light greenish gray fine- to medium-grained poorly sorted quartzose calcareous sandstone, at top and bottom of unit	5	298
Test Well 9-T		
SE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 8, T. 6 S., R. 4 W.		
Soil, red and yellow; chert rubble	20	20
Tuscumbia Limestone:		
Limestone, white to very light gray, medium-grained, in part oolitic.	12	32

Table 5.—*Sample logs of test wells in Morgan County, Ala.*—Continued

	Thickness (feet)	Depth (feet)
Test Well 9-T--Continued		
Tuscumbia Limestone--Continued		
Limestone, light-gray to medium-light-gray, medium-grained, in part oolitic.	18	50
Limestone, yellowish-gray to medium-olive-gray, medium-grained, in part oolitic; light-bluish-gray to medium-bluish-gray chert; some light-brownish-gray chert, completely silicified limestone	62	112
Limestone, yellowish-gray to light-olive-gray, fine- to medium-grained, in part oolitic, dolomitic near bottom of unit.	48	160
Fort Payne Chert:		
Upper unit:		
Limestone, yellowish-gray to light-olive-gray, very fine to medium-grained, dolomitic, in part oolitic	27	187
Limestone, yellowish-gray to light-olive-gray, and light-brownish-gray to brownish-gray, very finely crystalline to medium crystalline, in part dolomitic; very light brownish gray to brownish-gray chert; bluish-white to bluish-gray chert.	25	212
Limestone, greenish-white to greenish-gray, fine- to medium-grained, in part finely crystalline; bluish-white to medium-bluish-gray chert	34	246
Middle unit:		
Limestone, yellowish-gray to very light olive gray and light-gray, very fine grained and very finely crystalline, dolomitic, in part silicified; bluish-white to medium-bluish-gray chert	24	270

Table 5.—*Sample logs of test wells in Morgan County, Ala.*—Continued

	Thickness (feet)	Depth (feet)
Test Well 9-T--Continued		
Fort Payne Chert--Continued		
Middle unit--Continued		
Dolomite, very light olive gray and greenish-gray to dark-greenish-gray, very fine to fine-grained, in part calcareous; very light olive gray and greenish-gray chert; bluish-white to medium-bluish-gray chert; very light olive gray very fine grained dolomitic limestone; some dark-greenish-gray shale	20	290
Lower unit:		
Dolomite, greenish-gray to dark-greenish-gray, very fine grained; greenish-gray to dark-greenish-gray, and medium-gray to medium-olive-gray chert, completely silicified dolomite; bluish-white to medium-bluish-gray chert; some dark-greenish-gray shale	47	337
Dolomite, light-greenish-gray to medium-greenish-gray, very fine grained; some bluish-white chert and yellowish-gray to olive-gray and brownish-gray chert, completely silicified dolomite	20	357
Dolomite, greenish-gray, very fine grained; white to yellowish-gray medium to coarsely crystalline limestone, probably composed of crinoid stems and stem plates; yellowish-gray to light-olive-gray chert; some light-bluish-gray chert	7	364
Shale, greenish-gray to moderate grayish-green, calcareous, dolomitic, silicified, lower part soft, clayey, probably Maury Formation in part	6	370

Table 5.—*Sample logs of test wells in Morgan County, Ala.*—Continued

	Thickness (feet)	Depth (feet)
Test Well 9-T--Continued		
Chattanooga Shale:		
Shale, olive-gray to olive-black and brownish-gray to brownish-black, pyritic; yellowish-white to dark-olive-gray fine-grained medium sorted quartzose calcite cemented sandstone at top and bottom of formation. .	12.5	382.5
Test Well 10-T		
NE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 15, T. 6 S., R. 4 W.		
Soil, red and yellow; chert rubble	20	20
Tuscumbia Limestone:		
Limestone, very light olive gray to medium-olive-gray, fine to very coarse grained, in part oolitic.	31	51
Limestone, very light olive gray to light-olive-gray, very fine to medium-grained, in part very finely crystalline	59	110
Limestone, very light olive gray to medium-olive-gray, very fine to very coarse grained and very finely crystalline; some bluish-white to medium-bluish-gray chert.	23	133
Limestone, light-greenish-gray to dark-greenish-gray, very fine to coarse-grained, in part very finely crystalline; some bluish-white to medium-bluish-gray chert.	24	157
Fort Payne Chert:		
Upper unit:		
Limestone, yellowish-gray to light-olive-gray, very fine to very coarse grained, in part silicified; light-olive-gray chert, completely silicified limestone; some bluish-white to bluish-gray chert	8	165

Table 5.—*Sample logs of test wells in Morgan County, Ala.*—Continued

	Thickness (feet)	Depth (feet)
Test Well 10-T--Continued		
Fort Payne Chert--Continued		
Upper unit--Continued		
Limestone, light-olive-gray, very fine grained and very finely crystalline, in part dolomitic; bluish-white to light-bluish-gray chert; some light-olive-gray chert	35	200
Middle unit:		
Limestone, light-olive-gray, very fine grained, in part very coarse grained and very finely crystalline, dolomitic; light-olive-gray, light-greenish-gray, and moderate yellowish-brown, very fine grained petroliferous dolomite; bluish-white to light-bluish-gray chert; some olive-gray shale.	22	222
Dolomite, light-greenish-gray, very fine grained and very finely crystalline, calcareous; bluish-white to light-bluish-gray chert; light-greenish-gray chert; completely silicified dolomite	15	237
Lower unit:		
Dolomite, greenish-gray, very fine grained and very finely crystalline; bluish-white to very light bluish gray chert	14	251
Dolomite, greenish-gray, very fine grained and very finely crystalline; bluish-white to very light bluish gray chert; calcite crinoid stems and stem plates	24	275
Limestone, greenish-white to light-greenish-gray, finely to very coarsely crystalline, mostly crinoid stems and stem plates; some bluish-white chert and dark-greenish-gray siltstone	17	292

Table 5.—*Sample logs of test wells in Morgan County, Ala.*—Continued

	Thickness (feet)	Depth (feet)
Test Well 10-T--Continued		
Fort Payne Chert--Continued		
Lower unit--Continued		
Dolomite, light-greenish-gray to greenish-gray, very fine grained to finely crystalline; calcite crinoid stems and stem plates; some bluish-white to very light bluish gray chert	30	322
Dolomite, light-greenish-gray to greenish-gray, very fine grained to finely crystalline; light-greenish-gray to greenish-gray chert, silicified dolomite; bluish-white to very light bluish gray chert; calcite crinoid stems and stem plates	18	340
Limestone, light-greenish-gray and pinkish-gray to medium-brownish-gray, very fine grained and finely crystalline, contains crinoid stems and stem plates; mixed bluish-gray and greenish-gray chert, contains calcite crinoid stem plates; greenish-gray silty shale; some greenish-gray siltstone; light-greenish-gray shale, probably the Maury Formation	7	347
Chattanooga Shale:		
Shale, medium-brownish-gray and dark-brownish-gray, in part sandy and silty, pyritic, contains Lingula sp. probably L. melie; pinkish-gray to medium-brownish-gray very fine to very coarse grained poorly sorted calcite cemented sandstone, mostly at bottom of the formation.	12	359

Table 5.—*Sample logs of test wells in Morgan County, Ala.*—Continued

	Thickness (feet)	Depth (feet)
Test Well 11-T		
NE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 13, T. 6 S., R. 4 W.		
Soil, yellowish-brown, sandy	20	20
Soil, yellow	15	35
Limestone boulders and sand, yellow	16	51
Tuscumbia Limestone:		
Limestone, yellowish-gray to light-olive-gray, medium- to coarse-grained, oolitic; light-olive-gray very fine grained to finely crystalline limestone	3	54
Limestone, light-olive-gray, very fine to coarse-grained, in part oolitic and silicified; light-bluish-gray and light-greenish-gray chert	66	120
Limestone, light-olive-gray, very fine to coarse-grained and finely crystalline, in part oolitic; light-greenish-gray to dark-greenish-gray very calcareous silty shale; some light-bluish-gray chert	40	160
Limestone, light-olive-gray, very fine to coarse-grained and finely crystalline, in part oolitic; some light-greenish-gray to dark-greenish-gray shale	40	200
Fort Payne Chert:		
Upper unit:		
Limestone, yellowish-white to light-olive-gray and greenish-gray, very fine to coarse-grained and finely crystalline, dolomitic, in part silicified; bluish-white to medium-bluish-gray, some light-olive-gray chert and medium-greenish-gray to dark-greenish-gray shale	70	270

Table 5.—*Sample logs of test wells in Morgan County, Ala.*—Continued

	Thickness (feet)	Depth (feet)
Test Well 11-T--Continued		
Fort Payne Chert--Continued		
Upper unit--Continued		
Limestone, yellowish-white to very light olive gray, very fine to coarse-grained, dolomitic, in part silicified; calcite crinoid stems and stem plates; bluish-white to medium-bluish-gray chert; medium-greenish-gray to dark-greenish-gray shale.	7	277
Middle unit:		
Dolomite, very light greenish gray to greenish-gray, moderate yellowish-brown at top of unit, very fine grained, in part very finely crystalline, 10 percent silicified, petroliferous; very light greenish gray to greenish-gray chert, completely silicified dolomite; bluish-white to very light bluish gray chert; some greenish-gray shale.	50	327
Lower unit:		
Chert, greenish-gray; greenish-gray chert, completely silicified dolomite; greenish-gray very fine grained and very finely crystalline dolomite.	18	345
Dolomite, light-greenish-gray, very fine grained and very finely crystalline, in part silicified; light-greenish-gray chert; light-bluish-gray chert	11	356

Table 5.—*Sample logs of test wells in Morgan County, Ala.*—Continued

	Thickness (feet)	Depth (feet)
Test Well 12-T		
$NE\frac{1}{4}NW\frac{1}{4}$ sec. 12, T. 8 S., R. 4 W.		
Soil, light-brown	11	11
Soil, dark-brown	3	14
Bangor Limestone:		
Limestone, greenish-gray, very finely to coarsely crystalline and very fine to medium-grained	23	37
Limestone, light-olive-gray, very fine to coarse-grained	66	103
Limestone, light-olive-gray, very fine to coarse-grained, very sandy, silty; some light-olive-gray shale near bottom of unit	22	125
Hartselle Sandstone:		
Sandstone, greenish-gray, very fine to medium-grained, poorly sorted, quartzose, very calcareous, calcite cemented	8	133

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